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REPORT 524

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Safety of U-Turns at Unsignalized Median Openings

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Safety of U-Turns at Unsignalized Median Openings

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By B. Ray Derr
Staff Officer
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This report presents guidelines for locating and designing unsignalized median openings. A methodology is included for comparing the relative safety performance of different designs. Primarily, geometric designers for both state and local agencies will benefit from the report, but it will also be useful to those discussing the impacts of installing medians with business and property owners.

Designs for nontraversable medians vary widely and the safety and operational effects of the different designs have not been well documented. A thorough review of the safety and operational effects of the various designs was needed, both for setting design policy and in project-level design.

Transportation agencies often face resistance to installing nontraversable medians on multilane highways. One of the arguments made is that the number of U-turning vehicles will increase. However, the effect of an increase in U-turns on the safety of the road is not clear. Studies attributing safety gains to a nontraversable median have not focused on the specific situation at the median opening, either isolated or at an intersection, where U-turns occur.

After a nontraversable median has been installed, agencies are often approached by abutting property owners who want a new median opening. Additional information would be helpful in reviewing these requests, determining if an opening should be allowed, and developing a design that does not unduly affect the safety or operation of the road.

In NCHRP Project 17-21, Midwest Research Institute and their subcontractors determined state and local agency design practices and policies related to unsignalized median openings for U-turns. After promising designs were identified, their effects on safety were assessed through field observation and crash data analysis. The knowledge gained was distilled into design guidelines and a methodology for comparing the expected safety performance of different designs.

CONTENTS

SAFETY OF U-TURNS AT UNSIGNALIZED MEDIAN OPENINGS

SUMMARY

The objective of this research was to determine the safety and operational effect of U-turns at unsignalized median openings. The safety performance of typical median opening designs were documented, and guidelines for the use, location, and design of unsignalized median openings were developed. The research scope included unsignalized median openings on all types of divided highways, but the focus of the research was on urban/suburban arterials because these present the greatest current challenge to highway agencies in access management.

A catalog of median opening designs representative of the designs that actually exist in the field was created. The catalog included 918 unsignalized median openings that were found in 62 arterial corridors located in seven states. Median openings were classified by type of geometry (conventional versus directional), number of intersection legs (midblock versus three-leg versus four-leg), presence of left-turn lane(s), and presence of loon(s), resulting in a total of 17 typical median opening designs.

Field studies to document how drivers behave in making U-turns and left turns at unsignalized median openings were conducted at 26 urban sites; supplementary manual traffic counts were also made at 77 median openings on urban arterials. In addition, field studies and/or manual traffic counts were made at 12 median openings on rural arterials. The primary field studies were conducted by videotaping traffic operations at selected median openings. Over 150 hours of videotape were reviewed to determine traffic volumes and to document traffic conflicts at various unsignalized median opening designs. Analysis of field data found that, for most types of median openings, most observed traffic conflicts involved major-road through vehicles having to brake for vehicles turning from the median opening onto the major road; however, for median openings at four-leg intersections without left-turn lanes on the major road, most of the observed traffic conflicts involved major-road through vehicles having to brake for vehicles turning left into the median opening.

Accident studies of existing median openings were conducted to determine the relative safety performance of median openings of various types. Out of 7,717 median-opening-related accidents, only 1% were identified as involving U-turns. However, it was also found that many accidents coded by the investigating officer as involving left-turn maneuvers, in fact, involved U-turn maneuvers. For this reason, accidents involving both U-turn and left-turn maneuvers had to be evaluated as a group.

The research results indicate that access management strategies that increase U-turn volumes at unsignalized median openings can be used safely and effectively. Analysis of accident data found that accidents related to U-turn and left-turn maneuvers at unsignalized median openings occur very infrequently. In urban arterial corridors, unsignalized median openings experienced an average of 0.41 U-turn plus left-turn accidents per median opening per year. In rural arterial corridors, unsignalized median openings experienced an average of 0.20 U-turn plus left-turn accidents per median opening per year. Based on these limited accident frequencies, there is no indication that U-turns at unsignalized median openings constitute a major safety concern. Because of the low median opening accident frequencies, no satisfactory regression relationships relating median opening accident frequency to the volume of U-turn and left-turn maneuvers through the median opening could be developed.

For urban arterial corridors, median opening accident rates are substantially lower for midblock median openings than for median openings at three- and four-leg intersections, and median opening accident rates are slightly lower for conventional three-leg median openings than for conventional four-leg median openings. Average median opening accident rates for directional three-leg median openings are about 48 percent lower than for conventional three-leg median openings, and average median opening accident rates for directional four-leg median openings are about 15 percent lower than for conventional four-leg intersections.

The report recommends that midblock median openings be considered, where appropriate, as a supplement or an alternative to median openings at three-leg or four-leg intersections. It is also recommended that directional median openings at three- or four-leg intersections, combined with directional midblock median opening(s), be considered as a supplement or an alternative to conventional median openings at three- or four-leg intersections.

The report presents guidelines for the use, location, and design of unsignalized median openings. The guidelines include a methodology for comparing the relative safety performance of alternative median opening designs.

CHAPTER 1

INTRODUCTION

BACKGROUND

Many state and local transportation agencies are considering installing nontraversable medians on multilane arterial highways to improve safety and travel times. Business and property owners often resist such improvements because they and their customers may be denied the opportunity for direct left-turn access to or from their property. Traffic destined for such locations must use alternate routes, some of which may involve making U-turns at nearby median openings. Figure 1 illustrates drivers making U-turn maneuvers at an unsignalized median opening.

It is often inconvenient for those denied direct left-turn access to use alternative routes to reach their destination, and the additional travel distance or time for using an alternative route may cause some delay that should be considered in the decision to implement the project. An argument has been advanced by some opponents of projects that restrict direct left-turn access that any increase in U-turns may pose a safety problem, potentially offsetting the anticipated safety benefits of restricting direct left-turn access. However, highway agencies currently are not able to respond to such arguments because the safety effects of increased U-turn volumes are largely unknown. Most before-after safety evaluations of projects involving median installation have focused on the effect of the median on safety within the project limits while, because of the alternative routes used by motorists to reach their destinations, some of the traffic and some of the accidents may have moved beyond the project limits.

Another concern of highway agencies is that, after a nontraversable median has been installed, highway agencies are often approached by property owners requesting that a median opening be installed to provide direct left-turn access to and from their property. Currently, highway agencies are unable to make such decisions on a sound engineering basis because they lack the necessary tools to evaluate the safety and operational effects of providing new median openings. There are median opening designs that might satisfy a property owner without unduly affecting the safety and traffic operations of a road, such as openings that permit left-turn maneuvers into a driveway, but prohibit left turns out of the driveway. However, there is little documentation of the safety and traffic operational effects of such designs.

RESEARCH OBJECTIVES AND SCOPE

The objectives of the research are as follows:

- To document the safety performance of median openings of various designs;
- To determine the safety and operational effects of U-turns at median openings; and
- To develop a guide for the use, location, and design of unsignalized median openings for U-turns.

The scope of the research includes median openings on all types of divided highways. However, although median openings on rural divided highways have been included, the focus of the research is on median openings on urban/suburban arterials because these present the greatest current challenge to highway agencies in access management.

The research scope is limited to unsignalized median openings in urban/suburban areas. Thus, the guidelines are specifically applicable to median openings without traffic signals.

ORGANIZATION OF THIS REPORT

This report presents the results of the literature review, the survey of highway agencies, a classification of typical median opening designs, a description of the data collection and analysis efforts, the results of the analyses, and conclusions and recommendations.

The remainder of this report is organized as follows. Chapter 2 summarizes current knowledge on the safety and operation of U-turns at unsignalized median openings. Current design policies and practices of state and local highway agencies related to median openings at unsignalized intersections are presented in Chapter 3. Chapter 4 presents a classification

Figure 1. U-turn maneuvers at unsignalized median opening.

of typical median opening designs used to accommodate U-turn maneuvers at unsignalized locations. The factors used in the classification process and the factors that influence the safety and operational performance of median openings are also identified in Chapter 4. The data collection and analyses are described in Chapter 5. The results of the analyses are presented in Chapter 6. Chapter 7 presents the conclusions and recommendations.

Appendix A presents the survey questionnaire distributed to state and local highway agencies concerning median openings at unsignalized intersections. Appendix B summarizes the highway agency responses to the survey questionnaire. Appendix C presents guidelines for the use, location, and design of unsignalized median openings.

CHAPTER 2

LITERATURE REVIEW

The objectives of the literature review are as follows:

- To document current knowledge of the safety effect of installing nontraversable medians on multilane highways,
- To identify key issues related to the increase of U-turns at unsignalized median openings, and
- To document the safety effect of installing or removing median openings.

The literature review includes the following issues related to the safety and operation of U-turns at unsignalized median openings:

- Location of median openings,
- Spacing of median openings,
- Safety of median openings,
- Median width,
- Median opening length,
- Safety effects of median treatments,
- Safety effects of increasing U-turn maneuvers through use of nontraversable medians,
- Left-turn lanes,
- Median acceleration lanes,
- Loons (i.e., paved aprons opposite median openings to assist larger vehicles in completing U-turn maneuvers),
- Sight distance at median openings,
- Indirect left-turn maneuvers,
- Access management,
- Spacing between access points, and
- Effects of adjacent traffic signals.

Literature related to each of these topics is summarized below.

LOCATION OF MEDIAN OPENINGS

The growing number of multilane highways with raised or depressed medians and without access control has created the need to provide median openings, or crossovers, at various locations along such facilities to permit vehicles to reach abutting property or reverse their direction of travel. Median openings, however, may also become points of increased congestion and accident exposure. Turbulence in traffic flow created by vehicles turning on or off high-speed roadways causes undesirable acceleration and deceleration maneuvers. Therefore, if traffic safety on multilane highways is to be preserved, the location of median openings must be given careful consideration. Some factors that influence median opening locations include the following:

- Spacing between median openings,
- Stopping sight distance,
- Intersection sight distance,
- Operating speeds,
- Length of turn lanes,
- Right-turn conflict overlap, and
- Size and type of traffic generator.

A committee of the Institute of Transportation Engineers developed a list of factors to consider in locating median openings (*1*). These included the potential number of left turns into driveways, length of frontage along the street right-of-way line of the property proposed to be served, distance of proposed opening from adjacent intersections or other openings, length and width of the left-turn storage lane as functions of the estimated maximum number of vehicles to be in the lane during peak hours, and traffic control. The committee noted the need to consider circuitous routing and added intersection turns that may be caused by closing a median opening.

Research for the Florida Department of Transportation (*2*) found that the overall reductions in the number of median openings along the roads studied in their analysis resulted in accident rate reductions, despite the increased through traffic flow and higher density of traffic flow per median opening. The Florida research, performed for four-lane and six-lane roadway sections, also found that the reduction in conflict points can improve traffic flow characteristics without increased risk of accidents at the remaining median openings.

Policies recommended at the national level for geometric design of median openings are presented in the AASHTO *A Policy on Geometric Design of Highways and Streets*, commonly known as the Green Book (*3*). The Green Book states that “median openings on divided highways with depressed or raised curbed medians should be carefully considered. Such openings should only be provided for street intersections or for major developments.” Regarding the location of median openings, the Green Book recommends that median openings designed to accommodate vehicles making U-turns only are needed on some divided highways in addition to openings provided for cross and left-turning movements. Separate U-turn median openings may be needed at the following locations:

- Locations beyond intersections to accommodate minor turning movements not otherwise provided in the intersection or interchange area. The major intersection area is kept free for the important turning movements, in some cases obviating expensive ramps or additional structures.
- Locations just ahead of an intersection to accommodate U-turn movements that would interfere with through and other turning movements at the intersection. Where a fairly wide median on the approach highway has few openings, U-turns are necessary for motorists to reach roadside areas. Advancing separate openings to accommodate them outside the intersection proper will reduce interference.
- Locations occurring in conjunction with minor crossroads where traffic is not permitted to cross the major highway but instead is required to turn right, enter the through traffic stream, weave to the left, U-turn, and then return. On high-speed or high-volume highways, the difficulty of weaving and the long lengths involved usually make this design pattern undesirable, unless the volumes intercepted are light and the median is of adequate width. This condition may occur where a crossroad with high-volume traffic, a shopping area, or other traffic generator that needs a median opening nearby and additional median openings would not be practical.
- Locations occurring where regularly spaced openings facilitate maintenance operations, policing, repair service of stalled vehicles, or other highway-related activities. Openings for this purpose may be needed on controlled-access highways and on divided highways through undeveloped areas.
- Locations occurring on highways without control of access where median openings at optimum spacing are provided to serve existing frontage developments and at the same time minimize pressure for future median openings. A preferred spacing at 400 to 800 m (0.25 to 0.50 mi) is suitable in most instances. Fixed spacing is not necessary, nor is it fitting in all cases, because of variations in terrain and local service needs.

SPACING OF MEDIAN OPENINGS

Increasing the spacing between median openings improves arterial flow and safety by reducing the number of conflicts and conflict points per mile, providing greater distance to anticipate and recover from turning maneuvers, and providing opportunities for use of turn lanes (*4*). It is increasingly recognized that spacing standards for unsignalized access points should complement those for signalized access points.

The Green Book makes the following recommendations on the spacing of median openings (*3*):

- Spacing between median openings should be adequate to allow for introduction of left-turn lanes.
- Median openings should reflect street or block spacing and the access classification of the roadway.
- Full median openings should be consistent with traffic signal spacing criteria.
- Spacing of openings should be consistent with access management classifications of criteria.

Research reported in *NCHRP Report 348* (*5*) indicates that several states have set median opening spacing criteria that range from 100 to 800 m (330 to 2,640 ft). These criteria are mainly applicable in suburban and rural environments. The report also presents minimum desired spacing of unsignalized median openings at driveways as a function of speed. This spacing ranges from 113 m (370 ft) at 48 km/h (30 mph) to 278 m (910 ft) at 88 km/h (55 mph). In addition, the report suggests the following guidelines be considered for the spacing and design of median openings on divided roadways:

- The spacing of median openings for signalized driveways should reflect traffic signal coordination requirements and the storage space needed for left turns.
- The spacing of median openings for unsignalized driveways should be based on a roadway's function or access level and the environment in which the roadway is located (e.g., rural) and should be conducive to signalization.
- Median openings for left-turn entrances should be spaced to allow sufficient storage for left-turning vehicles.
- Median openings at driveways could be subject to closure where volumes warrant signals, but signal spacing would be inappropriate.
- Median openings should be set back far enough from nearby signalized intersections to avoid possible interference with intersection queues, and storage for left turns must be adequate.

TRB Circular 456 (*6*) indicates that median openings generally should relate to the street or block spacing. Thus, where cross-streets are placed at regular intervals, these intervals will influence median opening spacing. The Circular recommends that access points on both sides of the road should be aligned on undivided highways. Where this is not possible, sufficient left-turn storage should be provided by establishing a minimum offset distance. Driveways should be offset from median openings by the following:

- At least 60 m (200 ft) when two low-volume traffic generators are involved,
- The greater of 60 m (200 ft) or the established median opening spacing interval when one major traffic generator is involved, and

- At least two times the established median opening spacing interval when two major traffic generators are involved.

NCHRP Report 375 (*7*) found that very few state highway agencies have formal policies on the minimum spacing between median openings. Those agencies that do have criteria generally use a spacing between median openings in the range from 0.4 to 0.8 km (0.25 to 0.5 mi).

The Florida DOT *Median Handbook* (*8*) identifies the following factors that should be considered in determining the spacing of median openings:

- Deceleration length,
- Queue storage,
- Turn radius, and
- Perception/reaction distance.

Based on consideration of all of these factors, Florida has identified a 330-m (1,070-ft) spacing between median openings as being a realistic minimum for urban arterials.

SAFETY OF MEDIAN OPENINGS

Much of the safety research of median openings has been conducted at intersections on divided highways. These studies generally document the safety performance of the intersection as a whole, but usually do not provide specific information on the safety performance of the median opening area by itself. Furthermore, safety research on midblock median openings (i.e., median openings not located at intersections or driveways) is limited and usually addresses a "system" or combination of intersections and midblock median openings, such as for indirect left-turn treatments. However, even research on divided highway intersections that is broader in scope than just the median opening area can provide valuable information on the safety performance of median openings.

Two published research studies have specifically addressed the safety performance of divided highway intersections, one in California and one in Ohio. A 1953 California study by McDonald (*9*) developed relationships between the number of accidents and traffic volume at divided highway intersections. This study was based on the accident experience over periods of 6 months to 5 years at 150 at-grade intersections on 290 km (180 mi) of rural divided expressways on the state highway system in California. Most of the intersections were two-way stop-controlled intersections, with stop control on the minor road and no control on the divided highway, although a few signalized intersections were included.

The analysis of these California data found that low-crossroad-volume intersections have higher accident rates per crossroad vehicle than do high-crossroad-volume intersections. The following relationship between the number of accidents and the traffic volume at divided highway intersections was developed:

$$N = 0.000783\, V_d^{0.455}\, V_c^{0.633} \qquad (1)$$

where

N = expected number of intersection accidents per year
V_d = ADT volume entering the intersection from the divided highway (veh/day)
V_c = ADT volume entering the intersection from the crossroad (veh/day)

This finding is evidence that concentrating cross-traffic at a few locations, by closing low-volume-crossroad intersections and providing frontage roads, may effectively reduce the number of intersection accidents.

The Ohio study, conducted by Priest (*10*) in 1964, included 3 years' worth of accident data for 316 at-grade intersections on divided highways with partial or no control of access. Most of the intersections were unsignalized; however, the author does not explicitly state the type of traffic control used at the intersections studied. Priest, like McDonald, also found that accident frequency is more sensitive to the crossroad traffic volume than to the divided highway traffic volume. Figure 2 illustrates the relationship between the average number of accidents per year and traffic volume at divided highway intersections developed by Priest.

In a 1967 study of divided urban and rural highways in North Carolina, Cribbins et al. (*11*) found that median openings do not necessarily experience high accident rates under conditions of low volumes, wide medians, and light roadside development. However, as traffic volumes and roadside development increase, the frequency of median openings does affect accident potential significantly. Specifically, Cribbins et al. found the following relationships:

- As traffic volumes increase, median openings experience a sharp increase in accident frequency. When combined with intensive roadside development, this increase in accident frequency becomes even more pronounced.
- Signalization of median openings does not necessarily reduce accident experience under high-volume conditions, but it makes the traffic flow more efficiently by distributing time for each movement.
- As roadside development increases, and crossovers of any type are permitted, accidents will increase.

In another study of multilane highways in North Carolina, Cribbins et al. (*12*) used the same data to determine the effects of selected roadway and operational characteristics on accidents on multilane highways. Cribbins et al. correlated eight highway characteristics with all injury accidents: median width, speed limit, traffic volume, level of service, access point index, intersection openings per mile, signalized openings per mile, and median openings per mile. The following conclusions were drawn from the analysis:

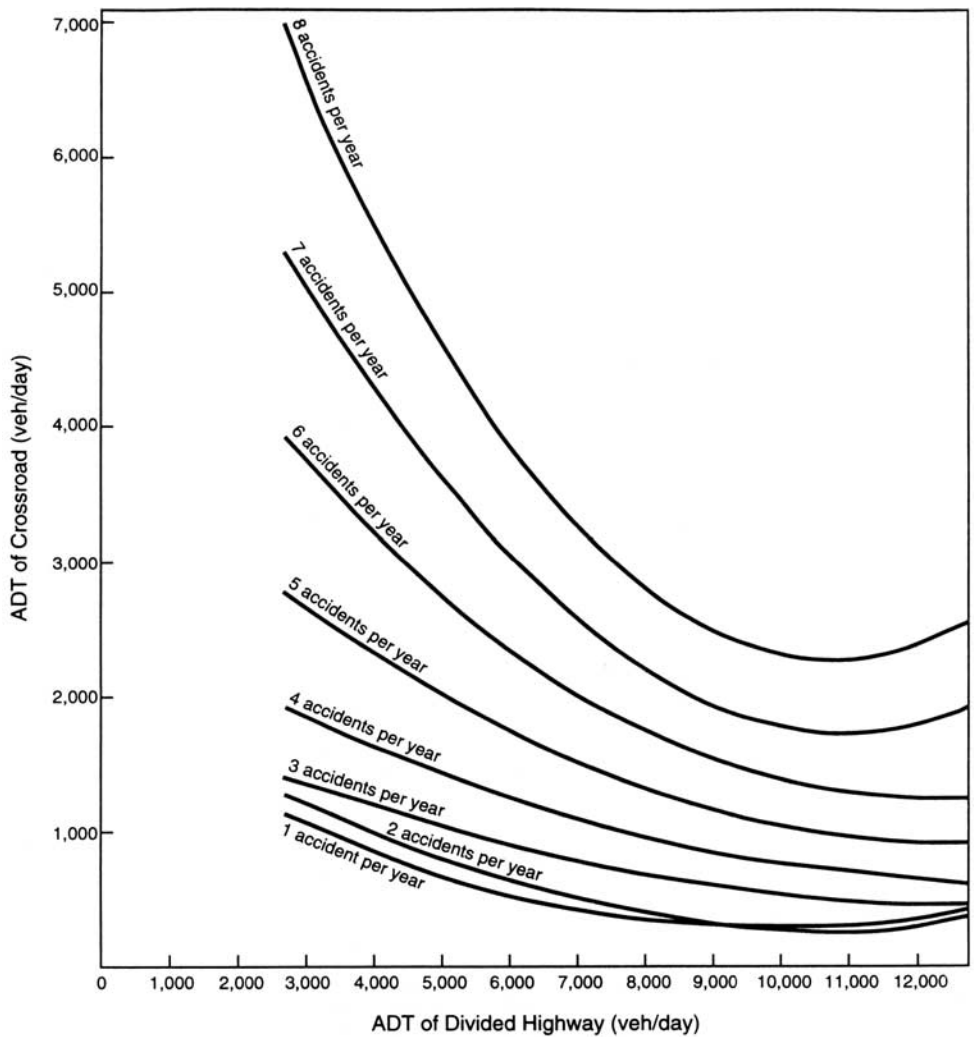

Figure 2. Average number of accidents per year related to traffic volume at divided highway intersections (10).

- The number of median openings, excluding intersections, affected the accident rate significantly.
- The two roadway characteristics having the least effect on the accident rate were median width and speed limit.
- Whenever storage lanes are installed at openings, the median-opening accident rate is no longer significantly affected by (1) the number of openings excluding intersections, (2) median width, (3) speed limit, or (4) ADT.

Research by Harwood et al. in *NCHRP Report 375* (*7*) found that the median width and median opening length have a strong influence on the safety performance of median openings. These issues are addressed in the next two sections of this report.

MEDIAN WIDTH

The safety and operational effects of median width at signalized and unsignalized intersections were evaluated extensively by Harwood et al. in *NCHRP Report 375: Median Intersection Design* (*7*). However, this evaluation addressed median width for median openings at intersections—not median openings at driveways or median openings used solely for U-turns. *NCHRP Report 375* used two separate approaches to address the relationship between median width and accidents at divided highway intersections: an accident study and a field observational study.

The traffic accident analysis of divided highway intersections was conducted for *NCHRP Report 375* with a statewide database of accident, geometric, traffic control, and traffic volume data for state highways in California.

The findings of the analysis concerning median width are as follows:

- At rural, four-leg, unsignalized intersections, accident frequency decreases as median width increases.
- At rural, three-leg, unsignalized intersections, no statistically significant relationship exists between accident frequency and median width.

- At urban/suburban, four-leg, unsignalized intersections, accident frequency increases with increasing median width over the range of median widths from 4 to 24 m (14 to 80 ft).
- At urban/suburban, three-leg, unsignalized intersections, the intersection accident frequency increases with increasing median width.

The field observational study in *NCHRP Report 375* investigated the effect of median width on three types of undesirable driving behavior as commonly observed in the median opening area at intersections on divided highways:

- 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.

Figure 3 illustrates side-by-side queuing of vehicles in an unsignalized median opening.

NCHRP Report 375 reached the following conclusions concerning the effect of median width on accidents and undesirable driving behavior at unsignalized intersections:

- At rural unsignalized intersections, the frequency of both accidents and undesirable driving behavior decreases as the median width increases.
- At suburban unsignalized intersections, the frequency of both accidents and undesirable driving behavior increases as the median width increases.

Based on these findings, *NCHRP Report 375* recommended that rural unsignalized intersections should have medians that are as wide as practical, as long as the median is not so wide that approaching vehicles on the crossroad cannot see both roadways of the divided highway. At suburban unsignalized intersections, by contrast, medians should generally not be wider than necessary to provide whatever left-turn treatment is selected. At specific intersections where substantial turning and crossing volumes of large 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.

One issue of interest to the research for *NCHRP Report 375* was how drivers making opposing left turns are influenced by the median width. Specifically, it was hypothesized that, at intersections with narrow medians, drivers making opposing left turns tend to turn in front of one another and, at intersections with wide medians, drivers making opposing left turns turn behind one another. Although no quantitative information exists on the median width at which drivers cease to turn in front of one another and begin to turn behind one another, an analysis of rural, unsignalized intersections found that, at intersections with median widths of less than 15 m (50 ft), vehicles making opposing left turns tend to turn in front of one another. In contrast, at intersections with median widths of more than 15 m (50 ft), vehicles making opposing left turns tend to turn behind one another. A similar pattern was found for suburban, unsignalized intersections with median widths of less than 15 m (50 ft). There were no comparable suburban, unsignalized intersections to verify whether the same turn-behind behavior observed at the rural, unsignalized intersections with median widths of more than 15 m (50 ft) occurred at similar suburban, unsignalized intersections.

A 1964 Ohio study by Priest found that, except at very low volume levels, intersection accident rates decrease with increasing median width (*10*). However, the difference in accident rates between medians less than 6 m (20 ft) wide and medians 6 to 12 m (20 to 39 ft) wide is greater than the difference in accident rates between medians with widths of 6 to 12 m (20 to 39 ft) and medians with widths of 12 m (40 ft) or more. These results are illustrated in Figure 4.

Figure 3. Side-by-side queuing at unsignalized median opening.

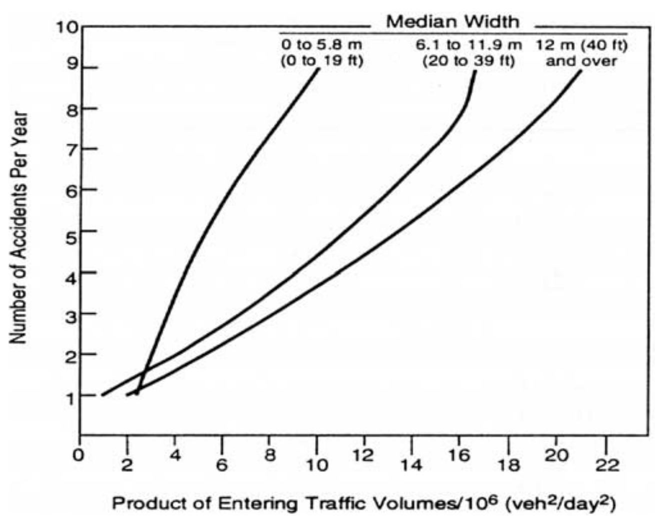

Figure 4. Variation of annual accident frequency at divided highway intersections as a function of median width and exposure index (the product of the ADTs of the intersecting roadways) (10).

A 1977 Purdue University study by Van Maren (*13*) developed relationships between geometric and traffic volume variables and accident experience at divided highway intersections. Van Maren found no statistically significant relationship between median width and intersection accident rate. The author speculated that this finding may have resulted because of the limited range of median widths (9 to 18 m or 30 to 60 ft) that were evaluated. However, this range includes most of the rural divided nonfreeways that have been built by highway agencies since the 1950s, including current practices.

Research sponsored by the Michigan Department of Transportation involved the collection and analysis of data for 1,503 km (934 mi) of Michigan state highways (*14*). Accidents on divided highway segments were compared with highway segments (mostly five-lane) with two-way left-turn lanes (TWLTLs). The analysis of the accident data with respect to the width of the median did not show any meaningful differences for divided highway segments that did not have traffic signals. The research found that divided highways with traffic signals may have lower accident rates with wider medians. However, the data were insufficient for conclusive findings on this issue.

The Florida *Median Handbook* (*8*) suggests that the appropriate median width is a function of the purpose which the median is to serve in a particular application, such as the following:

- Separation of opposing traffic streams,
- Pedestrian refuge,
- Left turn to side street,
- Left turn out of side street,
- Crossing vehicles,
- U-turns, and
- Aesthetics and maintenance.

Table 1 presents a summary of standards and recommendations for median widths, as presented in the Florida *Median Handbook*. The handbook recommends that extremely wide medians are needed to accommodate U-turn maneuvers by all design vehicles other than passenger cars.

MEDIAN OPENING LENGTH

The only literature found on the relationship of median opening length to safety is the research by Harwood et al. in *NCHRP Report 375: Median Intersection Design* (*7*). That report addressed the effect of median opening length on undesirable driving behavior. Most undesirable driving behavior at divided highway intersections arises from the competition for limited space on the median roadway between drivers traveling through the median in the same direction. *NCHRP Report 375* found that the frequency of undesirable driving behavior increases as median opening length increases at rural intersections and decreases as median opening length increases at suburban intersections.

SAFETY EFFECTS OF MEDIAN TREATMENTS (RAISED/DEPRESSED/FLUSH/TWLTL)

The treatment of roadway medians influences the safety and operational experience of a roadway as well as the access provided to adjacent developments. The four major types of median treatments are as follows:

- *Raised median*—A raised median is a nontraversable median separated from the traveled way by curbs. Raised medians are used where it is desirable to separate traffic traveling in opposite directions and limit left-turn movements. The area within the median can be either concrete or turf.
- *Depressed median*—A depressed median is a nontraversable turf median that separates traffic in opposite directions of travel and limits left-turn movements. As the name implies, a depressed median usually slopes away from the roadway to provide proper drainage. A depressed median has no curbs; the median is typically separated from the traveled way by pavement markings and shoulders.
- *Flush median*—A flush median is a paved area, at the same grade as the traveled way, that may be marked as a median or as a center two-way left-turn lane (see below).

TABLE 1 Minimum and recommended median widths (*8*)

Roadway type	Speed	Median width m (ft)	
Reconstruction Project	40 mph or less	5.0 (15.5)	Minimum
Reconstruction Project	45 mph	6.0 (19.5)	Minimum
Reconstruction Project	50 mph	7.0 (22.0)	Minimum
Four-lane highways with medians expecting significant U-turns and directional median openings with excellent positive guidance	All	9.0 (30.0)—single left turns 12.6 (42.0)—dual left turns	Recommended
Six-lane highways with medians expecting significant U-turns and directional median openings with excellent positive guidance	All	7.0 (22.0)—single left turns 10.6 (34.0)—dual left turns	Recommended

- *Two-way left-turn lane (TWLTL)*—A TWLTL is a center lane used for left turns from both directions of travel. At intersections, there is often a transition to conventional left-turn treatments.

The literature on these median treatments is extensive. Several NCHRP reports and other sources present safety comparisons of alternative median treatments.

Research by Bonneson and McCoy in *NCHRP Report 395*: *Capacity and Operational Effects of Midblock Left-Turn Lanes* (*15*) considered the relative traffic operational and safety performance of cross-section for arterials and highways that are undivided, divided by a median, or divided by a center TWLTL. Table 2 presents a comparison of these three alternative cross-sections, indicating which cross-section is preferred with respect to operational, safety, access, and other factors. *NCHRP Report 395* reviewed the relative safety performance of arterials with different cross-sections. Table 3 summarizes the safety performance of these cross-sections as reported by the following key sources in the literature: Bowman and Vecellio (*16*), Chatterjee et al. (*17*), Parker (*18*), Squires and Parsonson (*19*), McCoy and Ballard (*20*), Walton and Machemehl (*21*), and *NCHRP Report 282* (*22*).

NCHRP Report 420: Impacts of Access Management Techniques (*4*) presents a summary of individual studies that have analyzed the safety benefits of replacing TWLTLs with nontraversable medians on undivided highways. Eleven studies were reviewed: some where the benefits were based on before-and-after studies of the same roadway and some comparing accident rates for the two basic types of roads. The accident rate comparisons from the various studies are summarized in Table 4. In 15 out of the 16 comparisons shown in Table 4, the accident rates were reduced when a nontraversable median was installed in place of a TWLTL. *NCHRP Report 420* concluded that nontraversable medians appear safer than TWLTLs.

NCHRP Report 282: Multilane Design Alternatives for Improving Suburban Highways (*22*) presents a comparison of the safety, operational, and cost characteristics of selected multilane design alternatives for use in suburban areas. Advantages and disadvantages of each alternative are provided to assist in the selection of the most appropriate design for a given condition. The report states that the four-lane divided design alternative is best suited for use on major arterials with high volumes of through traffic and less than 45 driveways per mile. The five-lane TWLTL design alternative is most appropriate for suburban highways with commercial development, driveway densities greater than 45 driveways per mile, low-to-moderate volumes of through traffic, high left-turn volumes, and/or high rates of rear-end and angle accidents associated with left-turn maneuvers. Thus, *NCHRP Report 282* does not make a blanket statement about the relative safety of nontraversable medians and TWLTLs, but indicates that each has appropriate applications.

NCHRP Report 330: Effective Utilization of Street Width on Urban Arterials (*23*) evaluated various alternative strategies for reallocating the usage of street width without chang-

TABLE 2 Comparison of effects of three alternative cross-sections with differing midblock left-turn treatment types (*15*)

	"Preferred" Midblock Left-Turn Treatment[1]		
Comparison Factor	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.
[1]The "Preferred" left-turn treatment is based on the findings of the research and more commonly found opinion during a review of the literature.

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TABLE 3 Comparison of safety performance of alternative midblock cross-section as reported by studies in the literature (*15*)

ADT (Left-Turn Treatment; Reference Source)	Expected Accidents (miles/year) 10,000 TWLTL	10,000 Raised Median	10,000 Undivided	20,000 TWLTL	20,000 Raised Median	20,000 Undivided	30,000 TWLTL	30,000 Raised Median	30,000 Undivided	40,000 TWLTL	40,000 Raised Median	40,000 Undivided
NCHRP Report 282–1995 *(2)*	27	36	36	54	72	72	81	108	109	108	144	145
Bowman and Vecellio–1994 *(6)*	43	25	63	85	50	126	128	75	190	170	101	253
Chatterjee et al.–1991 *(7)*	55	46	NA	90	81	NA	125	116	NA	OOR	OOR	NA
Parker–1991 *(8)*	27	18	NA	43	32	NA	58	45	NA	73	59	NA
Squires and Parsonson–1989 *(9)*	-8	37	NA	31	56	NA	69	75	NA	108	94	NA
McCoy and Ballard–1986 *(10)*	31	NA	33	52	NA	OOR	OOR	NA	OOR	OOR	NA	OOR
Walton and Machemehl–1979 *(11)*	37	NA	NA	58	NA	NA	78	NA	NA	98	NA	NA
Average frequency	30	32	44	59	58	99	90	84	149	112	100	199
Standard deviation	7	5	10	8	9	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.

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TABLE 4 Synthesis of safety experience comparing TWLTLs with nontraversable medians by percent difference (*4*)

	Study & Location		YEAR	Description	Accidents TWLTL	Accidents Median	Accidents % Diff.	Accident Rates (Per Million VMT) TWLTL	Accident Rates (Per Million VMT) Median	Accident Rates (Per Million VMT) % Diff.	REMARKS
1	Bretherton, Womble & Parsonson (Georgia)	(1)	1990	Jimmy Carter Blvd. Atlanta	391	385	-2	8.09	6.47	-20	
2	Parsonson (Georgia)	(1)	1996	Memorial Blvd. Atlanta	947	523	-45	11.86	7.87	-34	Based on 1 year before (1988-1989), and 3 years after (1991-1993)
3	Banks et al. (Ontario)		1993	Hespeler Rd. Cambridge	45	33	-27	5.91	3.67	-38	Road widened to 6 lanes (2.8/km) midblock collisions.
4	Hartman and Spalett (Arizona)	(1)	1989	Phoenix	-	-	-	5.85	5.70	-3	
				Tucson	-	-	-	5.17	3.99	-22	
5	Bowman and Vecellio (Arizona, California, Georgia)	(1)	1994	Atlanta, Phoenix, Los Angeles/Pasadena	2,181	1,714	-21	5.56	6.42	15	CBD streets
				(15 road sections)	15,110	7,663	-49	6.89	3.79	-45	Suburban arterials
6	Parker (Virginia)	(1)	1983	17 Traversable sections 19 Median sections	-	-	-	6.11	4.42	-28	
7	Benac (Michigan)	(1)	1988	Four-lane arterials	-	-	-	9.56	4.07	-57	Based on 1985-1987 data
				Six-lane arterials				11.07	5.63	-49	
8	Squires and Parsonson (Georgia)	(1)	1989	57 Four-lane sections	-	-	-	8.99	7.67	-15	42 with TWLTL, 15 with medians
				25 Six-lane sections				10.82	8.15	-25	8 with TWLTL, 17 with medians
9	Parsonson (Georgia)	(1)	1996	State routes	-	-	-	6.23	3.67	-41	4 and 6 through lanes
10	Long, Gan, Morrison (Florida)	(1)	1993	Four-lane arterials	-	-	-	3.20	2.09	-35	
				Six-lane arterials				4.28	3.20	-25	
11	Margiotta and Chatterjee	(1)	1995	12 segments - median 13 segments - TWLTL	-	-	-	6.48	5.96	-8	

Note: (1) Represents comparison of different road sections.

ing the total curb-to-curb width. Table 5 presents the advantages and disadvantages of four-lane divided roadways and five-lane roadways with TWLTLs.

Research for the Florida Department of Transportation was performed for five roadway segments within the Central Florida area that underwent median modifications (*2*). Several of these segments also had other improvements, such as the addition of a through or auxiliary lane. The research results showed that the introduction of medians can greatly reduce collision potential and injuries. These reductions were found to occur as a result of the decrease in the number of conflict points. The research noted that conflict points are numerous along roadways with a continuous TWLTL. Conflict reductions with an associated decrease in collision potential may be achieved by either reducing the number of median openings or adding a median.

The FHWA sponsored research to quantify the safety effect of raised curb, TWLTL, and undivided cross-sections on vehicles and pedestrians (*16*). A total of 32,894 vehicle and 1,012 pedestrian accidents were analyzed from 234.8 km (145.9 mi) of unlimited access arterials in three large metropolitan areas. The research found that streets with raised medians in both central business districts (CBDs) and suburban areas had lower pedestrian accident rates than TWLTLs and undivided arterials. In suburban areas, arterials with raised-curb medians were found to have significantly lower accident rates than TWLTLs for rear-end, right-angle, and left-turn collisions. Raised-curb medians also were found to have significantly lower accident rates than undivided cross-sections for right-angle collisions. The research results also indicated that, in both CBDs and suburban locations, raised-curb medians had lower injury accident rates than either the TWLTL or undivided cross-sections.

Research sponsored by the Michigan Department of Transportation involved the collection and analysis of data for 1,503 km (934 mi) of Michigan state highways (*14*). Accidents on divided highway segments were compared with highway segments (mostly five-lane) with TWLTLs. The divided highway segments in Michigan generally have directional U-turn median crossovers that are also used for the indirect movement of left-turning traffic. Divided highway segments were found to have lower accident rates than TWLTLs for nearly every type of accident. The total accident rate (for all accident types) for the divided highway segments was approximately 50 percent of the total accident rate for highways with a TWLTL. Divided highways that exclusively have directional U-turn median crossovers were found to have approximately the same accident rate as divided highways that have conventional (bidirectional) median crossovers for unsignalized sections of highways. Signalized divided highways with directional crossovers were found to have about 50 percent of the accident rate of similar facilities with conventional median openings. However, the size of the data sample for this issue does not support conclusive findings.

The comparison between raised medians and TWLTLs has been the focus of numerous other research studies. Accident data assembled by Chatterjee et al. (*17*) and by Parker (*18*) indicate that raised-curb median segments have lower accident rates than TWLTL segments. Walton and Machemehl (*21*) developed accident prediction equations for roadway segments with TWLTLs. Not enough data were available to develop comparable equations for segments with raised medi-

TABLE 5 Advantages and disadvantages of four-lane divided roadways and five-lane roadways with TWLTLs alternatives (*23*)

Design alternative	Advantages	Disadvantages
Four-lane divided roadways	1. Provides additional lanes to increase capacity for through traffic movement 2. Reduces rear-end and angle accidents associated with left-turn maneuvers 3. Provides physical separation to reduce head-on accidents 4. Provides a median refuge area for pedestrians	1. Required street width may not be available 2. Increased delay to left-turning vehicles 3. Indirect routing required for large trucks 4. Lack of operational flexibility due to fixed median
Five-lane roadways with TWLTLs	1. Provides additional lanes to increase capacity for through traffic movement 2. Reduces delay to through vehicles caused by left-turning vehicles 3. Reduces frequency of rear-end and angle accidents associated with left-turn maneuvers 4. Provides spatial separation between opposing lanes to reduce head-on accidents 5. Increases operational flexibility	1. Required street width may not be available 2. No refuge area in median for pedestrians 3. May generate safety problems at closely spaced driveways and intersections

ans. Bonneson and McCoy (*24*) found raised-curb median treatments to be associated with fewer accidents than TWLTLs, especially for streets with average daily traffic (ADT) volumes exceeding 20,000. To determine the operational and safety effects of replacing a TWLTL with a raised median, the Gwinnett County Department of Transportation in Georgia compared the accident experience before and after construction of a raised median (*25*). An accident analysis determined that retrofitting a TWLTL with a 254-mm (10-in) concrete raised median reduces accidents. Squires and Parsonson (*19*) concluded that, on high-volume roadways, nontraversable medians have a lower crash experience than roadways with continuous TWLTLs. An analysis by Glennon et al. (*26, 27, 28*) found that TWLTLs have higher accident rates than raised medians where frequent driveways are found in combination with high arterial street volumes. Glennon et al. also found the raised median to be a more effective technique under higher traffic volumes. Margiotta and Chatterjee (*29*) performed a safety analysis of TWLTLs and raised medians. The study concluded that medians are generally safer than TWLTLs, but certain conditions exist where TWLTLs would have a more favorable safety experience. Regression analysis found that driveway density is an important contributor to accident rates for medians, but not for TWLTLs.

SAFETY EFFECTS OF INCREASING U-TURN MANEUVERS THROUGH USE OF NONTRAVERSABLE MEDIANS

The installation of a nontraversable median may prevent many direct left-turn movements previously accessible to motorists, forcing those motorists to use indirect routes and, thus, increasing the volume of U-turn maneuvers. The effect of this increase in U-turn volumes on the safety of the roadway is not well understood. However, several studies have identified issues related to U-turns at unsignalized median openings.

Research by Gluck et al. in *NCHRP Report 420: Impacts of Access Management Techniques* (*4*) documents the safety and operational experience in several states where directional U-turn median openings have replaced conventional median openings. The states reported that closing conventional median openings and replacing them with directional median openings improves safety. Specifically, *NCHRP Report 420* indicates that eliminating direct left turns from driveways and replacing them with indirect U-turn maneuvers results in a 20-percent reduction in accident rate. U-turn crossovers were found to have roughly one-half of the accident rates of roads with TWLTLs. The operational analysis in *NCHRP Report 420* identified several operational benefits of directional versus conventional median openings: shorter travel times, less delay, and increased capacity. The report states that right turns followed by U-turns can provide comparable, if not shorter, travel times than direct left turns from driveways under heavy volume conditions when the diversion distances are generally less than 0.8 km (0.5 mi).

In another study, conducted by Kach (*30*) in Michigan, the safety performance of directional median openings was compared with that of conventional median openings to determine the safety benefits that can be attributed to prohibiting left turns from the minor road. The mean intersection-related accident rates for directional median openings were found to be 15 percent lower than for conventional median openings. Similarly, the rates for intersection-related injury accidents were 30 percent lower for directional median openings than for conventional median openings. The study also showed substantial reductions in right-angle, rear-end, left-turn, and head-on accidents. In general, the results of this study indicate that directional median openings, where left turns are prohibited on the minor road, carry higher volumes at a lower accident rate than conventional median openings, where all turns are permitted.

Levinson et al. analyzed the safety benefits of directional versus conventional median openings as a function of traffic signal density for 123 segments constituting 364 km (226 mi) of divided highway in Michigan (*31*). The authors reported that directional median openings have one-third the accident rate of TWLTLs and about two-thirds the accident rate of conventional median openings. The operational benefits also included increased capacity, reduced travel times, and improved signal coordination.

In a paper presented at the 1996 annual meeting of the Transportation Research Board (*32*), Maki reported the safety results of replacing conventional median openings with directional median openings in Michigan. The Michigan DOT was experiencing capacity problems on an arterial because of interlocking left turns within the conventional median openings at major intersections. The results of replacing four conventional median openings with directional median openings were significant in reducing the number of crashes, particularly right-angle crashes. The average number of accidents per year was reduced from 32 to 13—a decrease of about 61 percent. Angle collisions were reduced by 96 percent, sideswipe collisions by 61 percent, and rear-end collisions by 17 percent. Injury accidents decreased by 75 percent.

Although the Florida *Median Handbook* (*8*) does not address specific safety issues related to U-turn maneuvers, it provides guidance on where a U-turn median opening should be considered. First, it lists several indicators that a U-turn median opening should be considered in advance of a signalized intersection:

- Level-of-service problems exist at the intersection.
- Heavy left-turn movements are present at the signal.
- Heavy conflicting right-turn movements are present at the intersection.
- Gaps in oncoming traffic would be beneficial at a separate U-turn opening.

- There is sufficient space to separate the signalized intersection and the opening.

The Handbook also provides three design options to accommodate U-turns: (1) wide medians, (2) median "bulb-out" or loon, and (3) flare-out (jughandles).

LEFT-TURN LANES

Vehicles turning left from a multilane highway may pose safety and operational problems at median openings. They not only increase conflicts with and delays to other vehicles, but also pose a major safety problem with the large speed differential between left-turning and through vehicles.

The FHWA National Highway Institute (NHI) has developed a short course on Access Management (*33*). The manual for the course recommends installing left-turn lanes at existing median openings to

- Allow turning vehicles to clear the through traffic lane with an acceptable speed differential,
- Provide queue storage without interference with through traffic,
- Reduce rear-end collisions and sideswipes, and
- Increase capacity and decrease delay.

The course also recommends increasing the length of an existing left-turn bay at all existing median openings where

- Deceleration in the through traffic lane results in an undesirable speed differential between left-turning vehicles and through traffic.
- The left-turn queue exceeds the length of the full-width left-turn lane.

Left-turn lanes are often installed at median openings to accommodate high left-turning volumes. *NCHRP Report 420* (*4*) summarizes the following safety benefits of left-turn lanes:

- They remove the turns from the through travel lanes, thus reducing rear-end collisions.
- They improve the visibility of oncoming traffic for vehicles turning left, thus reducing right-angle collisions.

Installation of left-turn lanes has been the focus of many research studies. Various safety-related factors have been documented based on the type of intersection (e.g., signalized, unsignalized, and four-leg) where the left-turn treatment was implemented. Although many of these studies focus on left-turn treatments on two-lane highways, the safety relationships can be useful for a broader range of roadway types, including divided arterials.

Parker et al. (*34*) determined that the addition of left-turn lanes at rural intersections along two-lane highways can reduce the potential for passing-related accidents. On urban four-lane roadways, McCoy and Malone (*35*) found that installation of left-turn lanes reduced rear-end, sideswipe, and left-turn accidents. Foody and Richardson (*36*) found that accident rates decreased by 38 percent with the addition of a left-turn lane at signalized intersections and by 76 percent at unsignalized intersections. Hauer (*37*) reported that left-turn channelization reduced accidents to varying degrees, depending on the intersection configuration; and Gluck et al. (*4*) reported accident rate reductions ranging from 18 to 77 percent as a result of the installation of left-turn lanes. A report by ITE indicates that median deceleration and storage lanes installed at intersections generally provide significant safety and operational benefits (*38*). Agent (*39*) performed an accident analysis of unsignalized intersections in Lexington, Kentucky, and found that the left-turn accident rate was 77 percent lower for intersections with left-turn lanes than intersections without left-turn lanes. Cribbins et al. (*11*) also reported that the number of rear-end collisions is less where storage lanes are provided.

When implemented with additional safety measures, left-turn lanes have been found to be very effective in increasing safety. Hauer (*37*) reported that the provision of left-turn lanes at unsignalized intersections, when combined with installation of curbs or raised medians, reduced accidents by 70, 65, and 60 percent in urban, suburban, and rural areas, respectively. When the channelization was painted, rather than raised, accidents decreased only by 15, 30, and 50 percent in urban, suburban, and rural areas, respectively. At signalized intersections, installation of left-turn channelization accompanied by a left-turn signal phase reduced accidents by 36 percent; however, without the left-turn phase, accidents decreased only by 15 percent. At unsignalized intersections, findings of a California study indicate greater reductions in accidents with the use of a left-turn lane in a raised median than with painted left-turn lanes (*40*). Similarly, Lacy (*41*) found that a left-turn lane, when coupled with several other safety improvements, reduced accident frequency by 35 percent and accident severity by 80 percent. Dale (*42*) found that installation of a traffic signal and left-turn channelization at intersections along rural two-lane highways reduced the total number of accidents by 19.7 percent, while the installation of a traffic signal without any channelization reduced the total number of accidents by only 6 percent.

Several predictive models and accident modification factors have been developed that indicate left-turn lanes have a positive effect on safety. Maze et al. (*43*) developed a model that predicted a reduction in left-turn accident rate of 5.5 percent as a result of the installation of a left-turn lane with permitted signal phasing and a reduction of approximately 35 percent from installation of a left-turn lane with protected/permitted signal phasing. Vogt (*44*) developed a model for a four-leg rural intersection of a four-lane major road with STOP-controlled two-lane minor roads, which yielded an accident reduction factor for total accidents of 38.4 percent as a result of the installation of a left-turn lane along the major road.

In another study, Harwood et al. (*45*) developed algorithms to predict the expected safety performance of rural two-lane highways. The prediction algorithms combined elements of historical accident data, predictions from statistical models, results of before-and-after studies, and expert judgments made by experienced engineers. As part of the research, an expert panel of engineers developed accident modification factors (AMFs) for specific geometric design and traffic control features. AMFs are used in the accident prediction algorithms to represent the effects of safety of the respective features. The base value of each AMF is 1.0. Any feature associated with a higher accident experience than the base condition has an AMF value greater than 1.0, and any feature associated with lower accident experience than the base condition has an AMF value less than 1.0.

In developing AMFs for the installation of left-turn lanes on the major-road approaches to intersections on two-lane rural highways, the expert panel reviewed various sources of information related to the accident reduction effectiveness of left-turn lanes. However, the panel did not find any well-designed before-and-after studies. Therefore, the panel combined results from several sources and developed AMFs for left-turn lanes, which are presented in Table 6. The AMFs represent a judgment by the panel. The panel estimated that installation of a left-turn lane along one major approach reduces intersection-related accidents by 18 to 24 percent, depending on the type of traffic control and the number of legs, and installation of left-turn lanes along both major approaches to a four-leg intersection reduces intersection-related accidents by 33 to 42 percent, depending on the type of traffic control.

Not all studies, however, have shown that left-turn lanes reduce accidents. Bauer and Harwood (*46*) found that left-turn lanes had a statistical association with higher frequencies of both total multiple-vehicle accidents and fatal and injury multiple-vehicle accidents. However, this result was not advanced by the authors as a basis for policy because the directions of specific effects in predictive models often represent the surrogate effects of other variables, rather than the true effect of the variable of interest. At unsignalized intersections, McCoy and Malone (*35*) determined there was a significant increase in right-angle collisions with installation of a left-turn lane. However, at unsignalized intersections on rural two-lane highways, McCoy et al. (*47*) found no significant difference in rear-end and left-turn collision rates between intersections with and without left-turn lanes. Poch and Mannering (*48*) also found some situations in which accidents of specific types increased with installation of left-turn lanes.

NCHRP Report 348 (*5*) indicates that, although turning lanes may be required for some or all access locations to major activity centers, they are not always required for smaller developments. The report cites reference materials, such as the *Highway Capacity Manual* (*49*), that should be consulted for information to help guide the decision of whether turn lanes are needed.

An emerging issue in the design of left-turn channelization is the restriction in sight distance that opposing left-turn vehicles cause one another. As an indication of this safety problem, David and Norman (*50*) determined that for ADT volumes between 10,000 and 20,000, four-leg intersections with opposing left-turn lanes had more accidents than those without. A potentially effective countermeasure for safety problems where opposing left-turn lanes are present is to eliminate the sight restrictions by offsetting the left-turn lanes, as shown in Figure 5. *NCHRP Report 375* reviewed the safety performance of a limited set of tapered and parallel offset left-turn lanes and found no safety problems (*7*). Both McCoy et al. (*51*) and Joshua and Saka (*52*) developed procedures to compute the amount of offset required for clear sight lines. However, no evaluations of the accident reduction effectiveness of offset left-turn lanes have been found. Although offset left-turn lanes have been used primarily at signalized median openings, they have been used by at least two agencies at unsignalized median openings. Offset left-turn lanes are a potential concern because they may make U-turn maneuvers more difficult to complete because they move the starting point for the U-turn maneuver closer to the opposing roadway. This potential problem is not addressed in the literature.

In another study, Harwood et al. (*53*) conducted a before-and-after evaluation of the safety effects of providing left- and right-turn lanes for at-grade intersections. Geometric design, traffic control, traffic volume, and traffic accident data were gathered for 280 improved intersections, as well as for 300 similar intersections not improved during the study

TABLE 6 Accident modification factors for installation of left-turn lanes on the major-road approaches to intersections on two-lane rural highways (*45*)

Intersection type	Intersection traffic control	Number of major-road approaches on which left-turn lanes are installed	
		One approach	Both approaches
Three-leg intersection	STOP sign[a]	0.78	–
	Traffic signal	0.85	–
Four-leg intersection	STOP sign[a]	0.76	0.58
	Traffic signal	0.82	0.67

[a] STOP signs on minor-road approach(es).

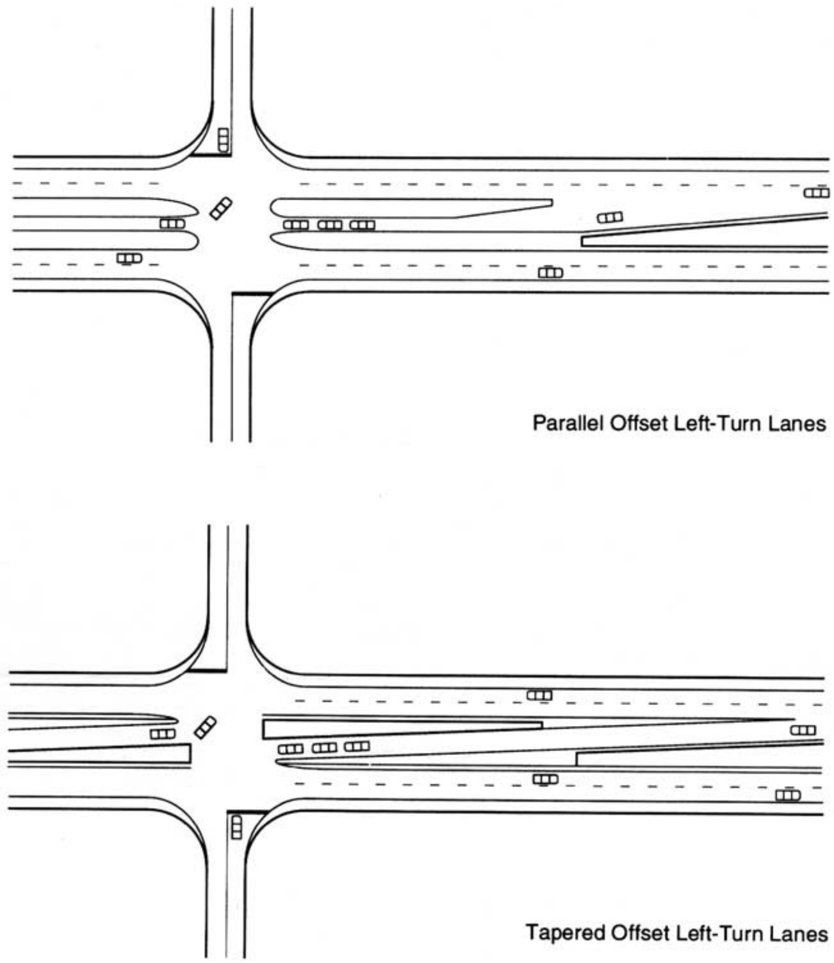


Figure 5. Examples of offset left-turn lanes (3).

period. The research developed quantitative safety effectiveness measures for installation design improvements involving added left-turn lanes and added right-turn lanes. The research concluded that added left-turn lanes are effective in improving safety at signalized and unsignalized intersections in both rural and urban areas. More specifically, the research concluded that

- Installation of a single left-turn lane on a major-road approach would be expected to reduce total intersection accidents at rural unsignalized intersections by 28 percent for four-leg intersections and by 44 percent for three-leg intersections.
- At urban unsignalized intersections, installation of a left-turn lane on one approach would be expected to reduce accidents by 27 percent for four-leg intersections and by 33 percent for three-leg intersections.
- At four-leg urban signalized intersections, installation of a left-turn lane on one approach would be expected to reduce accidents by 10 percent.

Based on the results of this study, the AMFs for turn lanes in Table 6 have been revised as shown in Table 7.

MEDIAN ACCELERATION LANES

Median acceleration lanes are increasingly used at intersections on high-speed divided highways. They provide vehicles turning left onto a divided highway from a minor road with a path to accelerate to an appropriate speed before entering the through travel lanes. Median acceleration lanes provide both safety and operational benefits in that the entering vehicles do not cause vehicles on the major roadway to decelerate substantially.

Median acceleration lanes can allow a full median opening to operate with some of the characteristics of a directional median opening. Figure 6 illustrates a typical divided highway intersection with median acceleration lanes.

In *NCHRP Report 375* (*7*) four intersections with one or more median acceleration lanes were studied with accident field data. These studies found that median acceleration lanes

TABLE 7 Accident modification factors for installation of left-turn lanes on the major-road approaches to intersections on two-lane rural highways (*53*)

Intersection type	Intersection traffic control	Number of major-road approaches on which left-turn lanes are installed	
		One approach	Both approaches
Three-leg intersection	STOP sign[a]	0.56	–
	Traffic signal	0.85[b]	–
Four-leg intersection	STOP sign[a]	0.72	0.52
	Traffic signal	0.82[b]	0.67[b]

[a] STOP signs on minor-road approach(es)
[b] based on results in Reference 45

can enhance the operation of intersections on divided highways. In particular, median acceleration lanes reduce the likelihood that vehicles making a left turn from a crossroad approach will need to stop in the median.

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. *NCHRP Synthesis of Highway Practice 281: Operational Impacts of Median Width on Larger Vehicles* (*54*), recommends the provision of median acceleration lanes to minimize the likelihood that larger vehicles will be required to stop in the median opening area. Median acceleration lanes normally allow vehicles turning left onto the divided highway to proceed without stopping, except when 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.

In 1982, ITE conducted a survey of highway and traffic agencies in Canada and the United States concerning current use of median acceleration lanes and TWLTLs (*38*). Given that median acceleration lane use was found to be limited, there was insufficient information for a quantitative analysis. However, some of the advantages and disadvantages reported by the agencies include the following:

Advantages:

- Median acceleration lanes reduce delays when traffic volumes are high.
- Median acceleration lanes provide higher merging speeds.
- Median acceleration lanes are useful if the acceleration lane is long enough to allow a safe merge.
- Median acceleration lanes reduce accidents.

Disadvantages:

- It is difficult to merge from median acceleration lanes because of blind spots.
- Median acceleration lanes are not used properly by drivers.
- Median acceleration lanes create anxiety to through traffic.

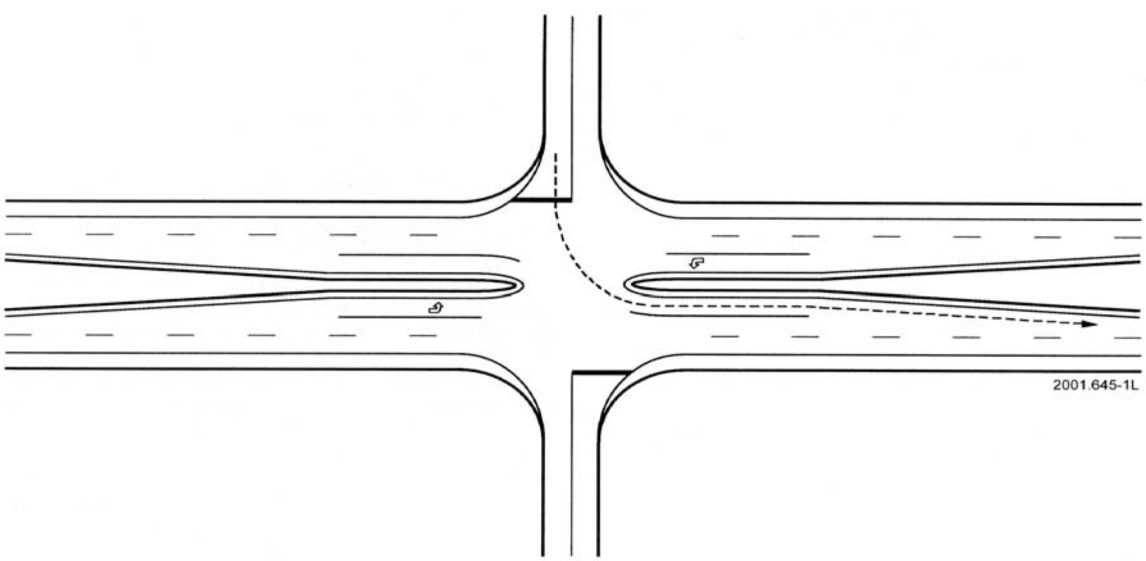


Figure 6. Typical divided highway intersection with median acceleration lanes (7).

- Median acceleration lanes create conflicts.
- Median acceleration lanes are unexpected and unfamiliar to drivers.
- The benefits of median acceleration lanes do not warrant the construction costs.

The agencies also stated that median acceleration lanes are most effective at high-speed T-intersections on rural roads.

Median acceleration lanes can improve the operation of directional median openings by helping U-turning vehicles to accelerate and merge with traffic on the through roadway. There are no data on whether median acceleration lanes at conventional median openings create additional conflicts for drivers making U-turn maneuvers.

LOONS TO ASSIST LARGER VEHICLES IN COMPLETING U-TURN MANEUVERS

A common problem associated with the use of directional crossovers for indirect left turns is the difficulty of larger vehicles to negotiate U-turns along cross-sections with narrow medians. This situation often affects the operation and safety of commercial vehicles that typically require more space in order to perform a U-turn maneuver. One possible solution to this problem is the construction of a loon. Loons are defined as expanded paved aprons opposite a median crossover. Their purpose is to provide additional space to facilitate the larger turning path of commercial vehicles along narrow medians. Figure 7 presents a typical loon design.

The genesis of the term "loon" is not clear, but it appears to be coming into common use. Loons appear to have been used at directional median openings, but the concept may be applicable to conventional median openings as well.

A study by Sisiopiku and Aylsworth-Bonzelet (*55, 56*) evaluated the operation, placement, and safety of existing loons at directional median openings in western Michigan. The Michigan DOT has placed several loons along a 47-km (29-mi) corridor of divided roadway to facilitate the larger turning radii of commercial vehicles performing indirect left turns. Field data (including geometrics, posted speed limits, sign types and location, and traffic control) and 5 years' of accident data were collected for the analysis. Results of the study indicate that directional crossovers with loons experienced a high percentage of fixed-object and sideswipe crashes. Specifically, the following safety concerns were found at loons:

- Fixed-object crashes with delineator posts, sign posts (in the median and along the mainline), and guardrail;
- Sideswipe crashes involving vehicles merging into mainline traffic from the loon;
- Sideswipe crashes involving mainline traffic attempting to use the right-turn lane and crashing with U-turning vehicles that turned from the crossover into the loon and then proceeded directly into the right-turn lanes; and
- Commercial vehicles backing up and parking within the crossover.

An operational analysis concluded that loons provide commercial vehicles with the extra pavement necessary to complete the U-turn maneuver required by indirect left-turns along narrow medians. Use of advance warning signs to improve driver expectancy is recommended. Finally, the authors present guidelines for the design and placement of loons.

SIGHT DISTANCE AT MEDIAN OPENINGS

Intersection sight distance (ISD) is an important design and operational consideration at all intersections, but may be even more important at divided highway intersections, including unsignalized median openings, where the median may increase the ISD requirements or may contain sight obstructions that reduce the ISD. U-turn maneuvers should not be encouraged at locations with limited sight distance.

Both *NCHRP Report 383: Intersection Sight Distance* (*57*) and *NCHRP Report 375* (*7*), identify situations where ISD requirements for divided highway intersections may differ from undivided highway intersections. *NCHRP Synthesis of Practice 281: Operational Impacts of Narrow Medians on Larger Vehicles* (*54*) identifies sight distance as an important issue in determining locations where U-turns by larger vehicles should be permitted or encouraged. The Florida *Median Handbook* (*8*) also addresses sight distance issues at median openings.

NCHRP Report 383 (*57*) presents revised ISD models that have been adopted by AASHTO and incorporated into the

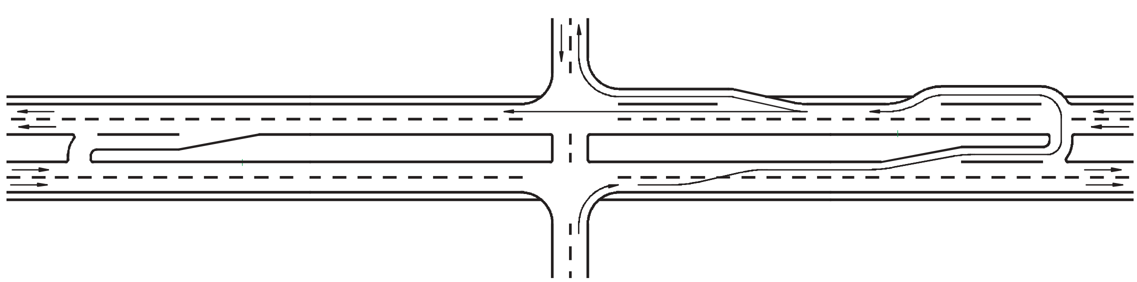


Figure 7. Typical loon design at a directional median opening (55, 56).

2001 Green Book (*3*). Addressing the unique nature of intersections on divided highways, the report states that these intersections may have substantial sight-distance concerns for left-turning vehicles. Despite the provision of stopping sight distance (SSD) along each roadway, sight obstructions in the median could limit left-turn sight distance. Furthermore, opposing left-turn vehicles on divided highways may be aligned in such a way that they become sight obstructions to one another, blocking the view of oncoming traffic on the major road. The sight restrictions created by opposing left-turn vehicles can be minimized by the use of parallel and tapered offset left-turn lanes.

NCHRP Report 375 (*7*) recognizes that ISD at divided highway intersections is complicated by the presence of the median on the major road, which may increase the ISD requirements at some intersections or may contain sight obstructions that reduce the ISD. The Green Book (*3*) considers ISD to be adequate when drivers at, or approaching, an intersection have an unobstructed view of the entire intersection and of sufficient lengths of the intersecting highways to permit them to anticipate and avoid potential collisions. Adequate ISD requires unobstructed sight distance along both approaches of both intersecting roadways, as well as across the clear sight triangles. Adequate clear sight triangles are required both for drivers approaching an intersection where they are not required to stop and for drivers who are stopped at an intersection waiting to proceed safely to cross a major roadway or to turn left or right onto a major roadway.

ISD requirements for crossing and turning maneuvers at divided highway intersections are generally increased with median width until the median becomes wide enough to store a vehicle. If the median is wide enough to store a vehicle, then the intersection operates as two separate intersections, because drivers can cross the near roadway and stop in the median, if necessary, before crossing or turning into the far roadway. In this case, the sight distance requirements of the intersections with the two roadways of the divided highway can be determined separately.

NCHRP Synthesis of Practice 281 (*54*) discusses alternative improvement techniques that can be implemented to mitigate the problems encountered by larger vehicles at divided highway intersections with narrow medians. When sight distance for left-turn vehicles is limited by opposing through vehicles, this report recommends the following mitigation techniques at unsignalized intersections:

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

The Florida *Median Handbook* (*8*) acknowledges that crossing and turning maneuvers onto a divided highway from a minor road or driveway can be performed as two separate operations. The stopped vehicle must first have adequate sight distance to depart from a stopped position and cross traffic approaching from the left. The crossing vehicle may then stop in the median prior to performing the second operation. The second move requires the necessary sight distance for vehicles to depart from the median, to turn left into the crossroad, and to accelerate without being overtaken by vehicles approaching from the right.

The handbook also presents recommended sight distance values for U-turns at unsignalized median openings—these values are provided here in Table 8.

Finally, the Florida *Median Handbook* (*8*) discusses sight distance issues related to opposing left-turn vehicles and suggests that vehicles turning left from opposing left-turn lanes restrict each other's sight distance unless the lanes are sufficiently offset. A positive offset of 0.6 m (2 ft) is recommended when the opposing left-turn vehicle is a passenger car and 1.2 m (4 ft) when the opposing left-turn vehicle is a truck.

INDIRECT LEFT-TURN MANEUVERS

Indirect left-turn maneuvers include the use of jughandle roadways before a crossroad, loop roadways beyond a crossroad, and directional median openings beyond a crossroad. Indirect left-turn treatments enable drivers to make left turns efficiently on divided highways, including highways with relatively narrow medians. The Michigan and New Jersey DOTs have used indirect left-turn treatments extensively; other state highway agencies have used them occasionally (*7*). Increasingly, Florida is limiting unsignalized median openings to left turns from the arterial roadway; hence, drivers wishing to turn left from a driveway must turn right and then make a U-turn or use some other alternative route. Design policies concerning

TABLE 8 Sight distance for U-turns at unsignalized median openings (*8*)

Speed (mph)	Sight distance (ft)
35	520
40	640
45	830
50	1,040
55	1,250
60	1,540
Speed (km/h)	**Sight Distance (m)**
60	160
70	200
80	260
90	380
100	470

Assumptions:
Design vehicle = passenger vehicle
Reaction time = 2.0 sec
Extra time needed in the U-turn maneuver
U-turn vehicle begins acceleration from 0 mph only at the end of the U-turn movement
Values are based on speed/distance/acceleration figures from the 1990 AASHTO *Green Book*
50-ft clearance factor

indirect left-turn treatments are addressed in the AASHTO Green Book (*3*).

Indirect left turns and U-turns are discussed on pages 709 through 716 of the Green Book (*3*). Several design alternatives are presented. Figure 8 presents a jughandle-type ramp or diagonal roadway that intersects a secondary crossing roadway. The driver exits via the jughandle-type ramp and makes a left turn onto the crossroad. For a U-turn maneuver, the driver makes an additional left turn onto the divided highway.

Figure 9 shows an at-grade loop that may be considered when the jughandle-type ramp would require costly right-of-way. Other factors favoring the at-grade loop include vertical alignment and grading costs.

Figure 10 illustrates a design that provides for indirect left turns to be made from the right, via separate turning roadways connected to a crossroad. Such arrangements eliminate left turns from the through lanes and provide storage for left-turning vehicles not available on the highway itself. The left-turning vehicles are able to cross the main highway with little extra travel time.

Figure 11 presents an indirect left turn for two arterials where left turns are heavy on both roads. Because lack of storage for left turns from the minor road would cause congestion, left turns from the minor road are prohibited. Left-turning traffic turns right onto the divided road and then makes a U-turn at a one-way crossover located in the median

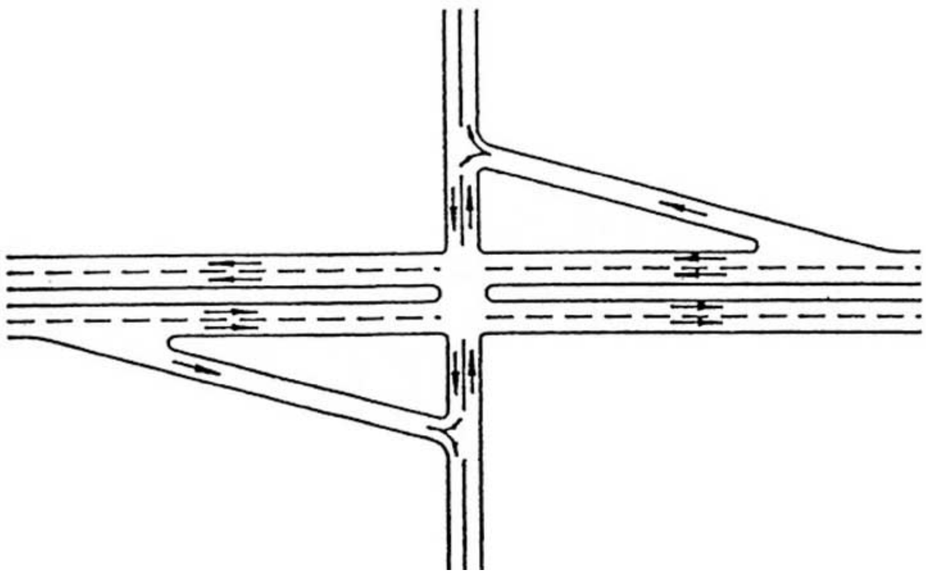


Figure 8. Jughandle-type ramp with crossroad (3).

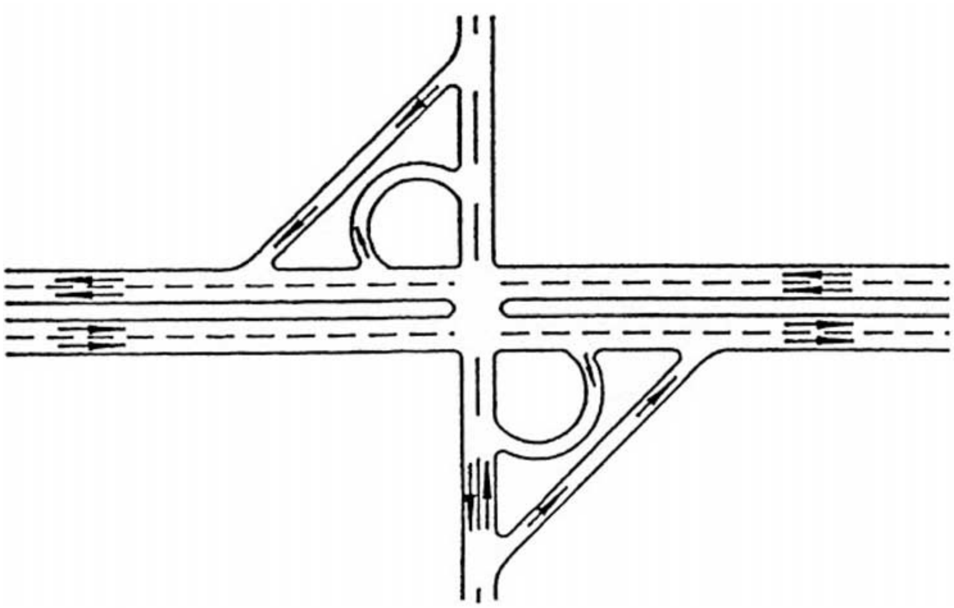


Figure 9. At-grade loop (surface loop) with crossroad (3).

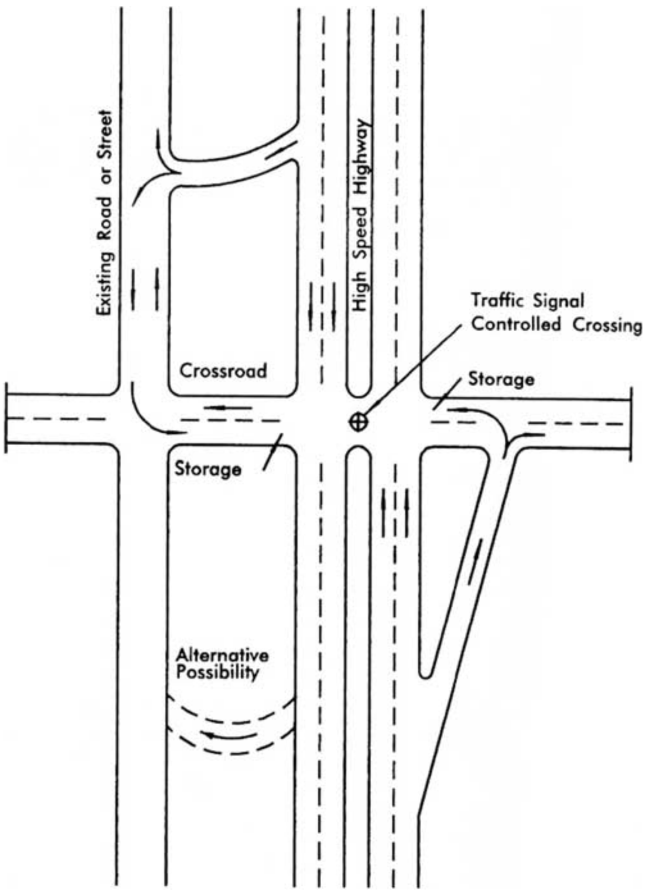


Figure 10. Special indirect left-turn designs for traffic leaving highway with narrow median (3).

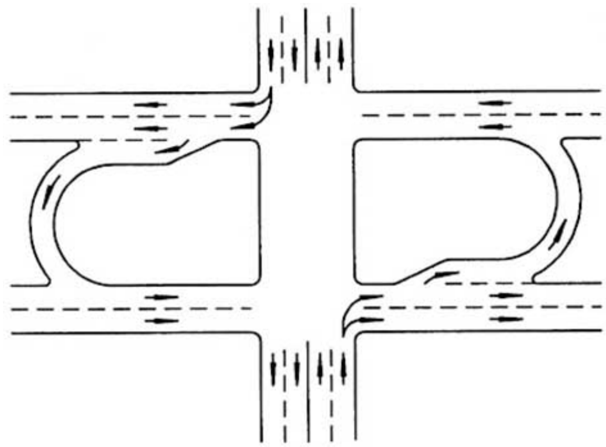


Figure 11. Indirect left turn through a crossover (3).

of the divided road. Auxiliary lanes are highly desirable on each side of the median between the crossovers for storage of turning vehicles.

In a series of ITE articles (*58, 59*), Hummer described seven unconventional left-turn design alternatives for urban and suburban arterials. The alternatives share two major principles: (1) reduce delay to through vehicles and (2) reduce and separate the conflict points at intersections. Hummer and Reid recently reviewed five of the seven alternatives—the median U-turn, bowtie, superstreet, jughandle, and continuous flow intersection—and summarized new information about each (*60*). After presenting the advantages and disadvantages of each alternative, the authors suggest when analysts should consider each alternative during feasibility studies and functional designs.

NCHRP Synthesis 281 (*54*) presents a discussion of indirect left-turns by larger vehicles. The report states that although the denial of left-turn access by a raised median 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 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. Where the median width of a divided highway at a median opening is narrow, no left-turn lane is provided, and the opposing traffic flow is high, drivers of larger vehicles that want 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, drivers of larger vehicles may proceed to the next major intersection to complete a U-turn maneuver or may use an indirect route to their destination, just as they would if no median opening were provided. There are no generally applicable estimates concerning how much delay to larger vehicles may result from such indirect routings.

NCHRP Report 420 (*4*) reports an estimated 20-percent reduction in accident rate by replacing direct left turns from driveways with right-turn/U-turn treatments. Table 9 summarizes the differences in accident rate at three unsignalized locations where direct left turns were replaced by indirect left turns.

Levinson et al. (*31*) present the safety and operational benefits of prohibiting left turns at signalized intersections along divided arterials in Michigan and installing directional U-turn crossovers downstream. Key features of the indirect left-turn treatments include the following:

- Two-phase signal operation at the major intersection where all left turns are prohibited;
- Directional U-turn crossovers for left turns located about 200 m (660 ft) on each side of the signalized intersection;
- Right-turn lanes on the major and minor roads;
- Left-turn lanes in the median of the major road for U-turn crossovers;
- Coordination of signals in each direction of travel along the major road to ensure progressions; and

TABLE 9 Accident rate differences—U-turns as alternate to direct left turns (*4*)

Location	Treatment	Difference in accident rate
US-1, Florida	Driveway left turns replaced by right-turn/U-turn	–22%
Michigan	Bi-directional crossover replaced by directional crossover	+14%
Michigan	TWLTL replaced by directional crossover	–50%

- Minor-road intersections that are unsignalized become two T-intersections, so there are no direct unsignalized crossings of the median.

The safety and operational benefits included lower accident rates, increased capacity, and reduced travel times.

Recently, the Florida DOT sponsored a study to evaluate the safety effects of replacing full median openings with directional median openings, resulting in the indirect left-turn treatment that forces drivers to make a right turn followed by a U-turn at a midblock U-turn lane (*61*). Over 250 sites were evaluated in this study, including 125 sites involving right turns followed by U-turns and 133 sites involving direct left turns. A cross-sectional comparison was used to measure the safety effects. The cross-sectional comparison method compares the crash rates of sample sites with two different egress designs: (1) direct left turns and (2) right-turns/U-turns. If the average crash rate of right-turn/U-turns is less than that of direct left turns at a certain statistical level of significance, it is presented that right-turn/U-turn movements could improve safety conditions. An assumption behind this comparison is that all the traffic patterns and geometric conditions remain consistent during the study period. The comparison concluded that on six-lane divided arterials with large traffic volumes, high speeds, and high driveway/side-street access volumes, the implementation of the right-turn/U-turn treatment leads to a statistically significant reduction in total crash rate (26.4-percent reduction) as compared with direct left turns. The injury/fatality crash rate for right-turn/U-turns is significantly less than that of direct left turns (32.0-percent reduction). For eight-lane arterials, replacing direct left-turn openings with right-turn/U-turn openings leads to a reduction in the crash rate while the four-lane group results in an increased crash rate; however, the results for the four-lane and eight-lane groups were not statistically significant because of small sample sizes.

ACCESS MANAGEMENT

The safe and efficient operation of the highway system depends heavily on the effective management of access to adjacent developments. Access management is generally understood to preserve the flow of traffic on the surrounding roadways, maintain mobility, and improve safety. A considerable amount of literature focuses on access management issues, and several studies have evaluated the relationship between safety and access management. Although none of these studies specifically address the safety at unsignalized median openings, the research that has established relationships between access density and safety can be useful in this study as well.

The research performed for *NCHRP Report 348* (*5*) investigated and documented the state of the art in access control and the broader concept of access management. The report defines access management as ". . . providing (or managing) access to land development while simultaneously preserving the flow of traffic on the surrounding road system in terms of safety, capacity, and speed." The report also defines the overall concept of access management, reviews current practices, and sets forth basic policy, planning, and design guidelines. The guidelines include possible legislative changes and enforcement procedures, as well as strategic design and operating guides.

NCHRP Report 420 (*4*) presents methods to predict and analyze the safety and traffic operational effects of selected access management techniques for different roadway variables and traffic volumes. Over 200 roadway segments, involving more than 37,500 accidents, were analyzed in detail. Accident rates were derived for various spacings and median types. Key findings related to accident density and safety at unsignalized intersections were as follows:

- Accident rates rise as the density of unsignalized access connections per mile increases.
- The number of affected through vehicles traveling in the curb lanes increases as high-volume driveways are spaced closer together. The likelihood of spillbacks across a driveway rises with either an increase in the traffic volumes entering driveways and/or the driveway density.
- Access spacing or setback distances on arterial roadways near freeway interchanges are generally inadequate for the weaving and left-turn storage movements that must be accommodated.

A planning and access management guide (*62*) for Florida cities and counties presents two recommendations related to the location of driveways:

- Construction of driveways along acceleration and deceleration lanes and tapers is discouraged because of the potential for vehicular weaving conflicts.
- Driveways across from median openings shall be consolidated whenever feasible to coordinate access at the median opening.

In a research study by Lall et al. (*63*), guidelines were developed for an access management program for the Oregon DOT. An analysis was performed on a 47-km (29-mi) section of Oregon Coast Highway 9 to determine the relationship between access density and accident experience and severity. The analysis demonstrated a relationship between frequency of accidents and density of access points. The results showed that the number of accidents increased as the number of access points increased along the highway.

Brown and Tarko developed impact models to predict crash frequencies based on the geometric and access control characteristics of a roadway (*64*). Negative binomial regression models were developed to predict the total number of crashes, number of property-damage-only crashes, and number of fatal and injury crashes. The significant factors included density of access points, proportion of signalized access points, presence of an outside shoulder, presence of a TWLTL, and presence of a median with no openings between signals. The results indicated that access control has a beneficial effect on safety.

The need to address the safety effects of U-turns at unsignalized median openings is a direct result of increased attention to access management. Highway agencies are installing more raised medians on arterials in response to access management guidelines. Median installation generally increases U-turn volumes and necessitates effective design of unsignalized median openings.

SPACING BETWEEN ACCESS POINTS

Access spacing is a key element of access management. An earlier portion of Chapter 2 addressed the effect on safety of the spacing between median openings. However, the spacing of access points between median openings is also an important aspect of access management. Access points introduce conflicts and friction into the traffic stream. Vehicles entering and leaving the main roadway often slow the through traffic, and the difference in speeds between through and turning traffic increases accident potential. The Green Book (*3*) states that "Driveways are, in effect, intersections . . . The number of crashes is disproportionately higher at driveways than at other intersections; thus their design and location merit special consideration." It is believed that increasing the spacing between access points improves arterial flow and safety by reducing the number of conflicts per mile, by providing greater distance to anticipate and recover from turning maneuvers, and by providing opportunities for use of turn lanes.

NCHRP Report 420 (*4*) presents an extensive summary of the safety research and experience associated with access spacing. The various studies point to one consistent finding: an increase in the number of access points translates into higher accident rates. The specific relationships vary, reflecting differences in road geometry, operating speeds, and driveway and intersection traffic volumes. Figure 12 shows the composite accident rates as presented in *NCHRP Report 420*.

In addition to the review of safety studies, a comprehensive safety analysis was performed using accident data from eight states. Accident rates were derived for various unsignalized access spacings and median types. The analysis showed that accident rates increase with total access points per mile in urban and rural areas. The authors concluded that in urban and suburban areas, each additional access point (or driveway) on undivided highways increases the annual accident rate by 0.07 to 0.11 accidents per million veh-km (0.11 to 0.18 accidents per million veh-mi) traveled. Each additional access point on highways with TWLTLs or nontraversable medians increases the annual accident rate by 0.06 to 0.08 accidents per million veh-km (0.09 to 0.13 accidents per million veh-mi) traveled. In rural areas, each additional access point (or driveway) increases the annual accident rate by 0.01 to 0.04 accidents per million veh-km (0.02 and 0.07 accidents per million veh-mi) traveled on undivided highways and on highways with TWLTLs or nontraversable medians, respectively.

TRB Circular 456 (*6*) presents a compilation of the current state and local practices for designing streets and highways from an access management perspective. The circular illustrates the basic considerations for spacing standards and

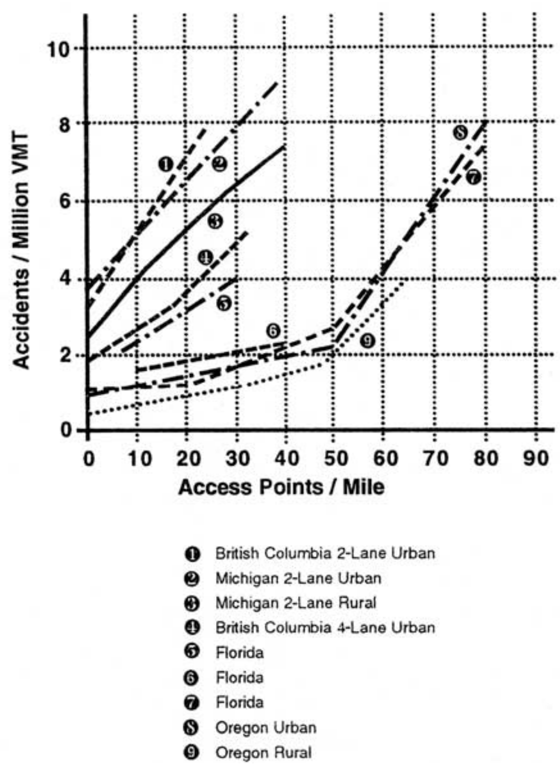


Figure 12. Composite accident rates as a function of access point density (4).

guidelines and describes current state, county, and local spacing requirements. Among the various agencies, there is little consensus on unsignalized intersection spacing; however sight distance requirements and driver response times are key parameters. The authors recognize the need for additional research on unsignalized spacing and corner clearance criteria and their applicability in various urban, suburban, and rural settings. Finally, the circular presents some established traffic engineering and roadway design and planning principles related to unsignalized access spacing:

- Limit the number of conflicts.
- Separate basic conflict areas.
- Reduce interference with through traffic resulting from turns into or out of a site.
- Provide sufficient spacing between at-grade intersections.
- Maintain progressive speeds along arterials.
- Provide adequate on-site storage areas.

NCHRP Report 348 (*5*) suggests that access spacing guidelines be keyed to allowable access levels, roadway speeds, and operating environments. The guidelines should apply to new developments and to significant changes in the size and nature of existing developments. It goes on to add that the guidelines do not have to be consistent with existing practices; because of historical conditions, access to land parcels that do not conform to the spacing criteria may be necessary when no alternative reasonable access is available. In addition, *NCHRP Report 348* observes that research and practices have not identified any clear method of establishing spacing standards for unsignalized intersections and that, moreover, many proposed guidelines have never been implemented. Standards may be based on speed, stopping sight distance, roadway function, type of traffic generator, or other considerations. The report presents guidelines for unsignalized driveway spacing that are based on speed, access level, size of activity center, and environment (e.g., urban). In general, spacing increases as the size of the activity center and operating speed increase. For example, for a minimum use activity in an urban area on a low-speed roadway with a high degree of access allowed, the spacing could be about 15 m (50 ft). In a rural area for a major activity on a high-speed roadway with allowable access more limited, the spacing could be about 150 m (500 ft).

In a manual for the NHI short course on Access Management (*33*), various conditions that should be considered in the determination of unsignalized access spacing are presented:

- Stopping sight distance,
- Intersection sight distance,
- Maneuver distance,
- Right-turn conflict overlap,
- Maximizing of egress capacity, and
- Corner clearance.

In a paper addressing the effect of street spacing on scale (*65*), Levinson compares the spacing and design of city streets and suburban highways, identifies the strengths and weaknesses of each, and suggests spacing guidelines for various urban and suburban environments. The paper demonstrates how the provision of arterial streets at closer intervals improves access opportunities, reduces traffic concentrations where these streets meet, and allows reduced cross-section.

In another paper by Levinson (*66*), a method is presented for predicting the safety of arterial roads based on arterial traffic volumes, access road volumes, and access density. The procedure applies the long-established relationship between intersection accidents and the product of conflicting traffic volumes. Safety indices are provided that relate only to the change in access density; these indices are generally consistent with those reported in *NCHRP Report 420* (*4*). The indices also show that the increase in accidents is equal to the square root of the increase in access density.

EFFECTS OF ADJACENT TRAFFIC SIGNALS

The effects of adjacent traffic signals on the operation of median openings and U-turn maneuvers include queue spillbacks that block a median opening and the influence of the adjacent signal on available gaps in traffic.

The Florida *Median Handbook* (*8*) addressed queue spillbacks and states that median openings should not be placed across regularly forming queues from neighboring intersections. Median openings placed too closely to an intersection cause both safety and operational problems. The safety problem is that when these queues build, "good Samaritans" might allow vehicles in the median opening through the queue without an adequate gap in the adjacent lane, creating a potential collision with a vehicle moving freely in the adjacent lane. A traffic operational problem is that when the queue in the through lane extends past the median left-turn lane, vehicles wanting access to the median opening are trapped in the queue and are unable to move into the turn bay until the queue advances.

CHAPTER 3

CURRENT DESIGN POLICIES AND PRACTICES OF HIGHWAY AGENCIES

This chapter presents the current design policies and practices of state and local highway agencies related to median openings at unsignalized intersections. Design policies at the national level are based on the AASHTO Green Book (*3*). Many states also have their own geometric design manuals, which may differ from the Green Book in some particulars, and their own access management manuals, which may also present policies concerning location and design of median openings.

The presentation of state and local agency design policies in this chapter of the report is based on responses to a survey questionnaire sent to state and local highway agencies. The questionnaire is presented in Appendix A of this report and the responses of highway agencies to the questionnaire are presented in Appendix B. The questionnaire addresses highway agency policies concerning location and design of median openings, treatment of U-turns at median openings, traffic operational and safety problems at median openings, and effectiveness of various mitigation measures.

SURVEY RECIPIENTS

The mailing list for the survey consisted of

- 50 state highway agencies and
- 109 local highway agencies (94 cities and 15 counties).

Thus, a total of 159 survey questionnaires were mailed.

The questionnaires for state highway agencies were generally sent to the state traffic engineer. The names and addresses of the state traffic engineers were determined from the membership roster of the AASHTO directory.

Most of the local highway agency engineers on the mailing list for the questionnaires were obtained from the ITE directory. The local agencies included approximately two major cities from each state and 15 selected urban or suburban counties. Rural counties were not surveyed because they are unlikely to operate many divided highways.

RESPONSE RATE

Table 10 summarizes the 65 responses to the 159 median opening surveys sent. Thirty-five state agencies, 23 cities, and 7 counties responded. Table B-2 in Appendix B lists the state and local highway agencies that responded to the survey. The overall response rate was 41 percent, including a response rate of 70 percent for state highway agencies and 28 percent for local highway agencies.

LOCATION AND DESIGN OF MEDIAN OPENINGS

The AASHTO Green Book provides guidance on the location and design of median openings in Chapter 6 (Collector Roads and Streets) and Chapter 9 (Intersections) (*3*). In both chapters, the Green Book recommends that median openings on divided highways with depressed or raised curbed medians only be provided for street intersections or for major developments and that spacing between median openings should be adequate to allow for introduction of left-turn lanes. In Chapter 9, the Green Book recommends that the design of a median opening and median ends should be based on traffic volumes, urban-rural area characteristics, and type of turning vehicles.

Highway agencies were asked about the types of median openings that they use. All agencies stated that they use conventional (i.e., nondirectional) median openings on divided highway. Most of the agencies use directional median openings either frequently or occasionally.

Location

Highway agencies were asked about the criteria they use to determine the location of median openings. The types of policies used by the responding agencies include AASHTO policy, state or local design policy, state or local access management policy, general guidelines (i.e., lists of factors considered as an informal policy), and engineering judgment. When asked about the factors considered in determining the location of median openings, the three most commonly cited factors were proximity to other median openings, traffic volumes, and locations and functional classes of public road intersections. Other frequently mentioned factors included sight distance, operational efficiency, safety, area type, speed, availability of sufficient length to accommodate left-turn lanes, and median width.

TABLE 10 Response rate for the highway agency survey

Agency type	Number of questionnaires mailed	Number of responses received	Response rate (%)
State agencies	50	35	70.0
Local agencies	109	30	27.6
Total	159	65	40.9

Spacing

Approximately one-half of the state and local highway agencies have formal policies concerning the minimum spacing between median openings. Most of the states and one of the local agencies that responded have different policies for rural and urban areas.

Tables 11 and 12 present median opening spacing policies of state and local highway agencies, respectively, that had numerical spacing policies that could be easily summarized. Some agencies had policies based on more variable criteria (e.g., left-turn queue lengths, sight distance, and traffic volumes), which are harder to summarize and are not included in the tables.

Table 11 shows that the states that have different spacing policies for rural and urban areas typically require higher median opening spacing in rural areas than in urban areas. The values reported for minimum median opening spacing for rural areas varied from 152 to 805 m (500 to 2,640 ft), while the comparable minimum spacing for urban areas varied from 91 to 805 m (300 to 2,640 ft); however, the average minimum median opening spacing was 427 m (1,400 ft) in rural areas and 268 m (880 ft) in urban areas.

Table 12 presents the minimum spacing between median openings for the local agencies that presented quantitative minimum median opening spacing values in response to the survey. The general trend of higher minimum median opening spacing at rural areas was still present, although the differences in median opening spacing between area types are not as large as those for state agencies.

Left-Turn Treatments

Most of the responding agencies require installation of left-turn lanes at unsignalized median openings in all or most cases. Some agencies stated that left-turn lanes are provided only where specific warrants are met; most respondents indicated that their warrants were based on left-turn volumes. Only two agencies responded that they have a formal policy on the conditions under which direct left-turn access to intersections or driveways is replaced by indirect left-turn treatment.

TREATMENT OF U-TURNS AT MEDIAN OPENINGS

Many state and local transportation agencies install nontraversable medians on multilane arterial highways to improve safety and travel times, often denying the opportunity for direct left-turn access to certain properties. Traffic destined for such locations must use alternate routes, some of which may involve making U-turns at nearby median openings. Other highway agencies are replacing conventional median openings that allow all traffic movements with directional median openings that allow only U-turn movements or allow only left-turn ingress to abutting developments; the left-turn egress movements would be made by turning right onto the arterial road and then making U-turn maneuvers downstream.

Consideration of U-Turn Maneuvers

In the survey questionnaire, highway agencies were asked if they have a formal policy for designing and locating median openings that makes specific reference to U-turn maneuvers. Only 16 percent of responding highway agencies indicated that they had a formal policy that addressed U-turn maneuvers. Most of these agencies rely primarily on AASHTO geometric design policies or some variation of AASHTO policy in their own guidelines. The factors mentioned in the policies for U-turn maneuvers at unsignalized median openings include

- Median width (based on design vehicles and potential for encroachment);
- Traffic conditions, including ADTs, truck volumes, and peak-hour turning movement counts;
- Sight distance;
- Ability to begin and end U-turn maneuvers on the inner lane next to the median;
- Accident frequency, particularly angle and rear-end collisions involving left- or U-turning vehicles;
- Specific threshold accident history criteria, such as five or more left-turn or U-turn-related accidents per year, similar to MUTCD requirements;
- Location of the median openings with respect to signalized intersections;
- Presence of exclusive left-turn lanes; and
- Availability of alternate locations for left- and U-turn maneuvers.

Prohibition of U-Turn Maneuvers

Highway agencies were asked whether U-turn maneuvers were permitted or not permitted at the following types of median openings:

- Median openings on rural highways,
- Median openings on urban/suburban arterials,

TABLE 11 State policies on minimum spacing between median openings

State	Minimum spacing (ft)		Comments
	Rural	Urban	
Alabama	600	300	
Arizona	1,320	660	For businesses generating high traffic volumes the minimum spacing is 330 ft
California	1,640	1,640	Unsure of possible differences between rural and urban criteria
Florida	1,320 2,640	330-660 660-1,320	Directional Conventional
Georgia	1,320	660	Maximum spacing 5,200 ft in rural areas and 1,320 ft in urban areas
Iowa	1,000	660	
Idaho	1,312	660	
Illinois	2,625 (minimum) 5,250 (desirable)	1,312	Longer minimum spacing used if needed to accommodate left turn lanes
Louisiana	1,500	500	
Maine	–	1,312-1,640 (minor arterial) 1,640-1,968 (major arterial)	Criteria apply to signalized median openings only
Michigan	1,320	660	Desirable spacing
Mississippi	1,760	880	
North Carolina	1,500	700 (< 45 mph) 1,000 (45-55 mph)	Urban spacing criteria vary with operating speed
Nebraska	1,000 (minimum) 2,000 (desirable)	600	
New Mexico	600	300	
Nevada	660	–	In urban areas, have criteria for access spacing rather than median opening spacing
Ohio	–	–	Have spacing criteria for driveways but not for median openings
Oklahoma	2,640 (minimum) 5,280 (desirable)	1,320	Longer minimum spacing used if needed to accommodate left turn lanes
Pennsylvania	1,500	1,500	
South Carolina	1,000	500	
Texas	1,320 – 2,640	1,320 – 2,640	
Virginia	700-1,000 (35-45 mph) 500-650 (50-70 mph)	700-1,000 (35-45 mph) 500-650 (50-70 mph)	Urban spacing criteria vary with design speed
Range	500 – 2,640	300 – 2,640	
Average	1,400	880	

- Unsignalized median openings, and
- Signalized median openings.

Table 13 summarizes the agency responses. Approximately 80 percent of the agencies that responded permit U-turns at all types of median openings. Nine agencies generally prohibit U-turn maneuvers at unsignalized median openings.

The agencies with formal policies concerning when to prohibit U-turns at median openings do so in the following situations:

- At all signalized intersections that have a right-turn overlap phase from a side-street approach on the left during the protected left-turn phase on the mainline roadway;

TABLE 12 Local agency policies on minimum median opening spacing

County	Minimum spacing (ft)		Comments
	Rural	Urban	
San Diego, CA	–	600	
Springfield, MO	–	500	
Fargo, ND	–	600 (arterials) 300 (collectors)	
Concord, NH	–	500 (commercial) 1,000 (suburban)	For arterials and collectors
Henderson, NV	–	660	
Maricopa County, AZ	660	660	For arterials and collectors
Pima County, AZ	1,320	1,320	
Riverside County, CA	330-1,320	330-1,320	Based on intersection spacing
Osceola County, FL	1,320 2,640	330-660 660-1,320	Directional Conventional
Broward County, FL	660	660	
Range	660 – 2,640	330 – 1,320	
Average	800	725	

- At any curve or on the approach to or near the crest of a grade where a U-turning vehicle cannot be seen by the driver of any other vehicle approaching from any direction within 150 m (500 ft) and at any intersection that does not meet the minimum sight distance criteria standards for U-turns as established by AASHTO;
- At intersections with a receiving pavement width of 7.3 m (24 ft) or less and at which the average vehicle cannot execute a U-turn maneuver in a single continuous movement;
- At any location for which a review of accident history finds that a U-turn restriction should be implemented, possibly only for certain times of the day;

TABLE 13 Number of highway agencies that permit U-turns at specific types of median openings

Agency type	Number (percentage) of agencies that permit U-turns at specific types of median openings				
	U-turns permitted		U-turns not permitted		Total
Median Openings on Rural Highways					
State agencies	26	(83.9)	5	(16.1)	31
Local agencies[a]	4	(100.0)	0	(0.0)	4
Total	30	(85.7)	5	(14.3)	35
Median Openings on Urban Highways					
State agencies	26	(83.9)	5	(16.1)	31
Local agencies	22	(84.6)	4	(15.4)	26
Total	48	(84.2)	9	(15.8)	57
Unsignalized Median Openings					
State agencies	26	(83.9)	5	(16.1)	31
Local agencies	22	(84.6)	4	(15.4)	26
Total	48	(84.2)	9	(15.8)	57
Signalized Median Openings					
State agencies	25	(80.6)	6	(19.4)	31
Local agencies	20	(76.9)	6	(23.1)	26
Total	45	(78.9)	12	(21.1)	57

[a] Includes county agencies only.

- Geometric design criteria;
- At signalized intersections; and
- If less than 11.3 m (37 ft) of width is available from the inside of the left-turn curb to the curb of the opposing lanes.

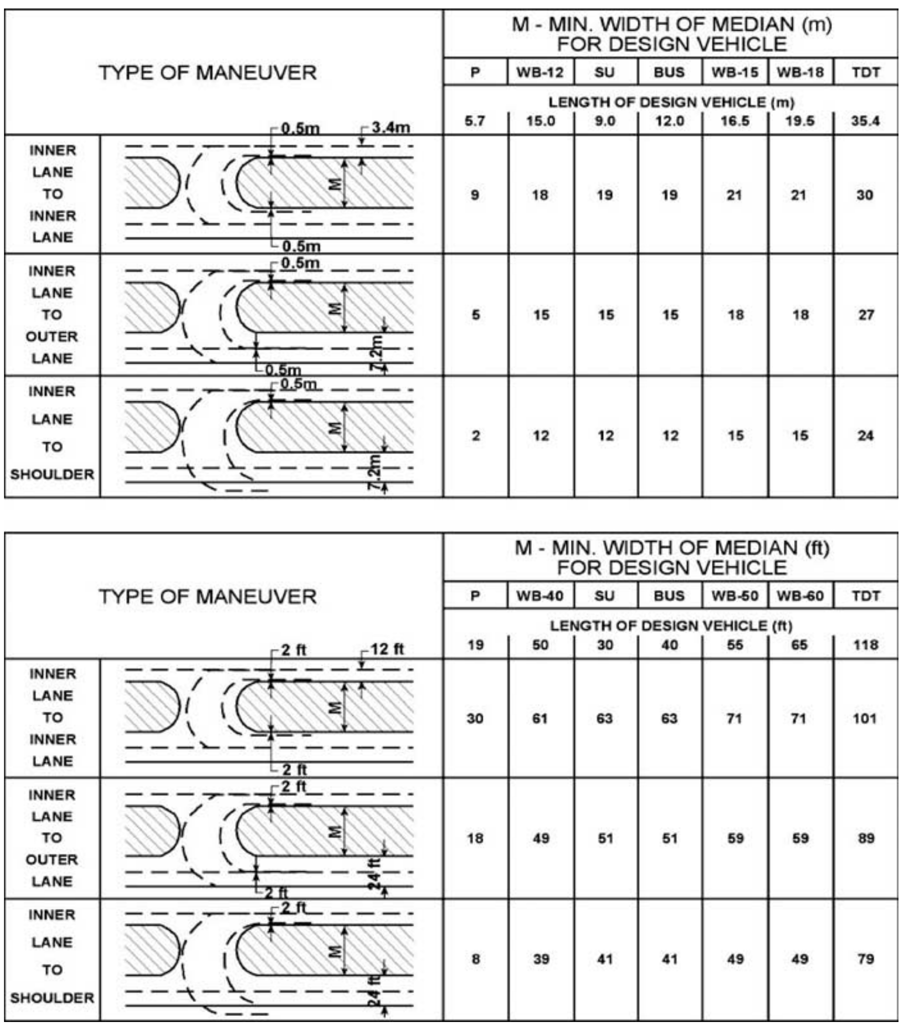
Two agencies stated that U-turns are prohibited at all median openings unless they are signed to permit U-turns.

Some agencies that did not have formal policies on where to permit or prohibit U-turns have informal guidelines that are presented below:

- U-turns are permitted only at locations having sufficient roadway width for maneuver.
- U-turns are prohibited based on accident rate or safety problems.
- U-turns are prohibited at signalized intersections where right-turn overlaps are allowed.
- U-turns are prohibited where they would create a substantial number of conflicts.
- U-turns are prohibited in some school zones.
- U-turns are prohibited to relieve congestion at median openings.
- U-turns are permitted at unsignalized median openings where a specific need is identified.
- U-turns are prohibited where a need is identified through engineering judgment.

MEDIAN AND ROADWAY WIDTHS TO ACCOMMODATE U-TURN MANEUVERS

The minimum median and roadway widths required to accommodate U-turn vehicles are key factors in whether a U-turn movement is permitted at a median opening. About half of the responding agencies stated that they follow the AASHTO *Green Book* (*3*) to determine the median and roadway widths required to provide for U-turns at unsignalized median openings. Figure 13 illustrates these AASHTO criteria, based on Green Book Exhibit 9-92. Several agencies



TYPE OF MANEUVER	M - MIN. WIDTH OF MEDIAN (m) FOR DESIGN VEHICLE						
	P	WB-12	SU	BUS	WB-15	WB-18	TDT
LENGTH OF DESIGN VEHICLE (m)	5.7	15.0	9.0	12.0	16.5	19.5	35.4
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

TYPE OF MANEUVER	M - MIN. WIDTH OF MEDIAN (ft) FOR DESIGN VEHICLE						
	P	WB-40	SU	BUS	WB-50	WB-60	TDT
LENGTH OF DESIGN VEHICLE (ft)	19	50	30	40	55	65	118
INNER LANE TO INNER LANE	30	61	63	63	71	71	101
INNER LANE TO OUTER LANE	18	49	51	51	59	59	89
INNER LANE TO SHOULDER	8	39	41	41	49	49	79

Figure 13. AASHTO minimum median widths to accommodate U-turns (3).

stated that they have no policy or use engineering judgment. The remaining agencies that responded have specific policies that differ from AASHTO Green Book; these policies are summarized below:

- Minimum median widths wider than those presented in the Green Book are used.
- U-turns are permitted on roads with a minimum width of six lanes.
- Minimum median widths in the range of 3 to 6 m (10 to 20 ft), based on the type of roadway, are used.
- U-turns are permitted on arterials with a minimum width of 12.8 m (42 ft), which includes a 1.2-m (4-ft) separator, 10 m (33 ft) of travel lane width, and 1.5 m (5 ft) of bike lane width.
- U-turns are permitted with a median width of 4.3 m (14 ft) and roadway width for one direction of travel of 7.9 m (26 ft).
- U-turns are permitted with a median width between 6 and 7 m (20 and 24 ft) and directional roadway width between 9 and 11 m (30 and 36 ft) for a four-lane divided highway.

When asked whether their criteria for design of median openings included provisions for U-turns by large vehicles (e.g. school buses, other buses, or large trucks), approximately one-half of the responding state agencies and one local agency indicated that such provisions are made.

TRAFFIC OPERATIONAL AND SAFETY PROBLEMS AT MEDIAN OPENINGS

Several factors affect the safety and operational performance of a median opening, e.g.,

- Degree of urbanization,
- Operating speeds,
- Access density,
- Roadway geometrics,
- Traffic volumes,
- Physical constraints, and
- Median width.

For example, it is well known that locations with fewer conflict points (i.e., where fewer traffic movements cross one another) are likely to experience fewer accidents than locations with more conflict points. Thus, it is likely that a median opening that serves U-turns only will operate more safely than one where U-turns use the same roadway as left-turn and crossing maneuvers. Similarly, a median opening that serves only one intersection or driveway would function like a three-leg intersection and would likely operate more safely than a median opening that serves intersection legs or driveways on both sides of the arterial roadway, which would function like a four-leg intersection.

Highway agencies were asked whether they had experienced safety or traffic operational problems at unsignalized median openings. Nearly 60 percent of the agencies that responded indicated that they had. The five most cited factors related to safety or operational problems at unsignalized median openings in decreasing order are as follows:

- Operational considerations (e.g., heavy U-turns or through volumes, and trucks),
- Median too narrow,
- Driveway nearby,
- Poor roadway geometry, and
- Roadway too narrow.

A more complete list of factors identified by highway agencies as related to the safety or operational problems they encountered at unsignalized median openings is presented in Appendix B.

MITIGATION MEASURES FOR SAFETY PROBLEMS

When asked if they have constructed improvement projects intended to mitigate safety and operational problems at unsignalized median openings, 37 percent of responding highway agencies indicated they have constructed improvement projects. Some of the mitigation measures for safety and operational problems cited are as follows:

- Removal of closely spaced median openings by replacing raised medians with TWLTLs;
- Replacement of conventional crossovers with directional crossovers;
- Installation of left-turn storage lanes;
- Installation of left-turn lanes with positive offset;
- Signalized intersections;
- Closure of median openings to allow left turns to align properly;
- Reconfiguring of median openings by channelizing or adding left-turn lanes to prevent congestion or confusion in the median opening;
- Installation of directional median openings to permit left turns from the major-road left-turn lane, but prohibit left turns and through movements from the minor road;
- Provision of a median opening at what formerly was a right-in/right-out driveway;
- Elimination of conventional median openings and replacement with jughandle U-turns;
- Installation of "No U-turn" signs; and
- Installation of raised/extended median to prevent U-turns.

Six of the agencies that constructed improvement projects indicated that they have conducted a formal before-and-after evaluation.

CHAPTER 4

CLASSIFICATION AND ASSESSMENT OF TYPICAL MEDIAN OPENING DESIGNS

A key objective of this research is to identify and classify those median opening designs typically used to accommodate U-turn maneuvers at unsignalized locations. A classification system of this type is presented in this chapter. This classification system identifies how particular median openings function and where they are located relative to other elements of the highway system. This chapter presents the factors used in the classification process, provides an overview of typical median designs, identifies the factors that influence the safety and operational performance of median openings, and presents typical combinations of median opening designs used along an arterial.

A further objective of the research is to estimate the safety and operational performance of particular types of median openings. This chapter of the report takes a step toward that objective by cataloging the advantages and disadvantages of particular types of median openings and establishing a framework within which their relative performance can be determined. The relative safety of various median opening designs is assessed on the basis of potential traffic conflicts. The specific safety and operational performance of median openings is presented in Chapter 6.

FACTORS USED IN CLASSIFICATION OF MEDIAN OPENING DESIGNS

The four key factors used to classify or describe the design of a median opening are

- Type of geometry,
- Degree of access served,
- Presence of left-turn lanes, and
- Presence of loons.

The first factor, type of geometry, determines which movements are possible at a median opening. Conventional median openings (sometimes referred to as "full median openings") typically permit all movements, while directional median openings may restrict certain movements. Jughandles are an indirect left-turn treatment that enable drivers to make U-turn and left-turn maneuvers efficiently on divided highways with relatively narrow medians.

The second factor, degree of access served, not only determines what movements need to be accommodated at a median opening, but also the number of potential conflict points a median opening will have. For example, a median opening that only serves U-turn maneuvers will have considerably fewer conflicting maneuvers than a median opening at a three- or four-leg intersection, where U-turns use the same roadway as left-turn and crossing maneuvers. Median openings can be classified by whether access points are present on neither side, on one side, or on both sides of the roadway. Access points at median openings may include either intersecting public roads or driveways.

Figures 14 through 18 illustrate median openings with various combinations of the first two classification factors: type of geometry and degree of access served.

The third factor used in the classification is whether or not a median opening has a left-turn lane. Median openings generally operate better when left-turn lanes are present to provide a deceleration and storage area for vehicles before they enter the median. In fact, the AASHTO Green Book specifically encourages the use of left-turn lanes at median openings to reduce or eliminate stopping on the through lanes (*12*).

The final factor in classification of median openings is whether or not a median opening is accompanied by a loon. A loon is an expanded paved apron on the shoulder opposite a median crossover. The purpose of loons is to provide additional space for larger vehicles (particularly trucks) to negotiate turns, and thus, to allow the installation of conventional or directional median openings along narrow medians. The provision of loons to serve U-turns by large vehicles is a new technique that formalizes past use of paved shoulders for the same purpose. Initial results by highway agencies that have used loons appear promising (*55*).

Based on the four factors discussed above, median openings can be classified based on their design characteristics as follows:

- Type of geometry (traffic movements permitted)
  - Conventional (all movements permitted),
  - Directional, and
  - Jughandle;

Figure 14. Conventional midblock median opening.

Figure 16. Directional median opening at three-leg intersection.

- Degree of access served
  - U-turn only (midblock median opening),
  - Access on one side (at three-leg intersection), and
  - Access on two sides (at four-leg intersection);
- Presence of left-turn lane
  - No left-turn lane present and
  - Left-turn lane present;
- Presence of loon
  - No loon present and
  - Loon present.

OVERVIEW OF TYPICAL MEDIAN OPENING DESIGNS

Using the first two classification factors (geometry type and degree of access served), typical median openings can be classified into the following seven categories:

1. Conventional Midblock Median Opening,
2. Directional Midblock Median Opening,
3. Conventional Median Opening at Three-Leg Intersection,
4. Directional Median Opening at Three-Leg Intersection,
5. Conventional Median Opening at Four-Leg Intersection,
6. Directional Median Opening at Four-Leg Intersection, and
7. Midblock Jughandle U-Turn Maneuvers.

These seven categories of median openings can be subdivided on the basis of the presence of left-turn lanes or loons and the types of turning maneuvers permitted. With these subdivisions, there are a total of 17 typical median opening designs. The following discussion presents each of the seven categories of median openings and the specific designs used for those openings. The discussion of each median opening design includes a figure with a diagram of each median opening design and a list of the advantages and disadvantages associated with each design.

Conventional Midblock Median Opening

A conventional midblock median opening permits vehicles to make U-turns, but does not provide separate channelized roadways for vehicles making U-turns in opposing directions. Median openings at midblock locations are appropriate on arterials where providing for U-turn maneuvers between intersections may improve operations at intersections by reducing the U-turn volumes at those intersections or reducing the amount of out-of-direction travel for vehicles trying to reach a destination without direct left-turn access. Conventional median openings are appropriate where U-turn volumes are relatively low, such that U-turn vehicles in opposing directions of travel create minimal interference with one another.

The conventional midblock median opening design is further classified into three subcategories based on the presence of left-turn lanes and/or loons:

Figure 15. Conventional median opening at three-leg intersection.

Figure 17. Conventional median opening at four-leg intersection.

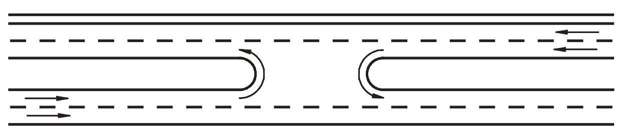
Figure 18. Directional median opening at four-leg intersection.

- Type 1a—Conventional Midblock Median Opening Without Left-Turn Lanes;
- Type 1b—Conventional Midblock Median Opening With Left-Turn Lanes; and
- Type 1c—Conventional Midblock Median Opening With Left-Turn Lanes and Loons.

Figures 19 through 21 illustrate these three median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Types 1b and 1c reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles. The presence of loons in Type 1c provides a widening in the pavement to accommodate U-turn movements by larger vehicles, such as emergency vehicles and trucks.

Figures 19 through 21 show opposing U-turning maneuvers passing in front of one another and, thus, not overlapping or conflicting. Where the opposing U-turns do not overlap, there are only four conflict points at each of the median opening types shown in the figures; a more complete discussion of conflict points is presented later in this chapter of the report. In some situations, not well defined at this time, but clearly a function of the size and shape of the median opening, U-turning vehicles may overlap (or turn behind one another). The possibility of these alternative maneuver types may create confusion between drivers making opposing U-turns. This issue is addressed further in the subsequent discussion

Type 1a—Conventional Midblock Median Opening Without Left-Turn Lanes



Advantages

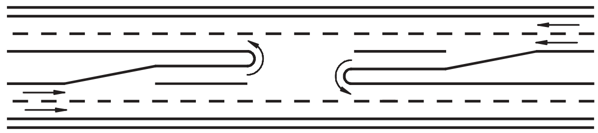
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.

Figure 19. Advantages and disadvantages of median opening type 1a—conventional midblock median opening without left-turn lanes.

Type 1b—Conventional Midblock Median Opening With Left-Turn Lanes



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.

Figure 20. Advantages and disadvantages of median opening type 1b—conventional midblock median opening with left-turn lanes.

of factors that influence the safety and operational performance of median openings.

Directional Midblock Median Opening

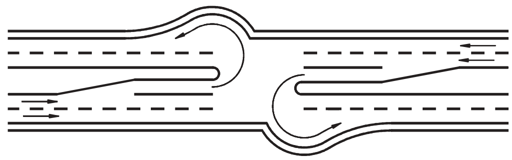
A directional midblock median opening permits vehicles to make U-turns and provides separate channelized roadways for vehicles making U-turns in opposite directions. Thus, opposing U-turn vehicles will not overlap. Median openings at midblock locations are appropriate on arterials where providing for U-turn maneuvers between intersections may improve operations at intersections by reducing the U-turn volumes at those intersections or reducing the amount of out-of-direction travel for vehicles trying to reach a destination without direct left-turn access. Directional median openings are appropriate where U-turn volumes are relatively high, such that U-turn vehicles in opposing directions of travel would otherwise interfere with one another.

The directional midblock median opening design is further classified into three subcategories based on the presence of left-turn lanes and/or loons:

- Type 2a—Directional Midblock Median Opening Without Left-Turn Lanes;
- Type 2b—Directional Midblock Median Opening With Left-Turn Lanes; and
- Type 2c—Directional Midblock Median Opening With Left-Turn Lanes and Loons.

Figures 22 through 24 illustrate these three median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Types 2b and 2c reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles. The presence of loons in Type 2c provides a widening in the pavement to accommodate U-turn movements by larger vehicles, such as emergency vehicles and trucks.

Type 1c—Conventional Midblock Median Opening With Left-Turn Lanes and Loons



Advantages

- Widening on the far side of the turn makes it possible to make a U-turn without stopping or backing and reduces interference between U-turn and through traffic, particularly for large vehicles.
- Without performing major reconstruction, additional space can be provided to facilitate the larger turning path of commercial vehicles along narrow medians.
- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- With no directional island, opposing U-turn vehicles may have to overlap.
- The presence of loons may make snow removal and other maintenance work more difficult.

Figure 21. Advantages and disadvantages of median opening type 1c—conventional midblock median opening with left-turn lanes and loons.

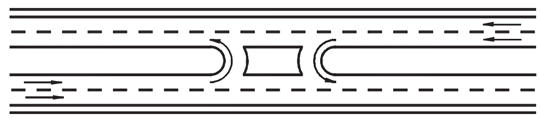
Conventional Median Opening at Three-Leg Intersection

A conventional median opening at a three-leg intersection permits vehicles on the major road to make U-turn movements on the major road and left- or right-turning movements onto the minor road. Vehicles on the minor road may make left or right turns onto the major road. No separate channelized roadways are provided for vehicles making U-turns in opposing directions. Thus, U-turn vehicles may overlap with opposing U-turn or left-turn vehicles. Median openings at three-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects. Conventional median openings are appropriate where it is desirable to allow left-turning movements from both the major road and the minor road (or driveway) and where U-turn volumes are relatively low, such that U-turn vehicles in opposing directions of travel create minimal interference with one another.

The conventional median opening design at a three-leg intersection is further classified into four subcategories on the basis of the presence of a left-turn lane and/or loon:

- Type 3a—Conventional Median Opening Without Left-Turn Lanes at Three-Leg Intersection;
- Type 3b—Conventional Median Opening With One Left-Turn Lane at Three-Leg Intersection;
- Type 3c—Conventional Median Opening With Two Left-Turn Lanes at Three-Leg Intersection; and
- Type 3d—Conventional Median Opening With Left-Turn Lanes and Loons at Three-Leg Intersection.

Type 2a—Directional Midblock Median Opening Without Left-Turn Lanes



Advantages

- This design prevents overlapping U-turns.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.

Figure 22. Advantages and disadvantages of median opening type 2a—directional midblock median opening without left-turn lanes.

Figures 25 through 28 illustrate these four median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Types 3b, 3c, and 3d reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles. The presence of loons in Type 3d provides a widening in the pavement to accommodate U-turn movements by larger vehicles, such as emergency vehicles and trucks.

Directional Median Opening at Three-Leg Intersection

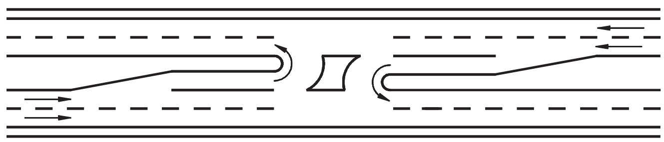
There are two types of directional median openings at three-leg intersections:

- Type 4a—Directional Median Opening for Left Turns from Major Road at Three-Leg Intersection; and
- Type 4b—Directional Median Opening for Left Turns onto Major Road at Three-Leg Intersection.

The first type, designated as Type 4a, permits vehicles to turn left off the major road onto the minor road and to make U-turn maneuvers on the major road, but does not permit vehicles to turn left from the minor road onto the major road. The second type, designated as Type 4b, permits vehicles to turn left or right from the minor road onto the major road and vehicles on the major road to make U-turn maneuvers, but does not permit vehicles to turn left off the major road onto the minor road. Median openings at three-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects.

Directional median openings are appropriate where U-turn or left-turn volumes are relatively high, such that a conventional median opening would experience considerable interference between vehicles entering the median opening. Directional median openings are also appropriate where there is a disproportionately high left-turn demand from either the major

Type 2b—Directional Midblock Median Opening With Left-Turn Lanes



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- This design prevents overlapping U-turns.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.

Figure 23. Advantages and disadvantages of median opening type 2b—directional midblock median opening with left-turn lanes.

road or the minor road and, therefore, either Type 4a or Type 4b would accommodate the needs of the intersection. Directional median openings are desirable where an intersection is going to be signalized, given that these openings only affect major-road traffic in one direction and that effective two-direction signal coordination can be maintained (*5*).

Figures 29 and 30 illustrate these two median opening designs and their advantages and disadvantages.

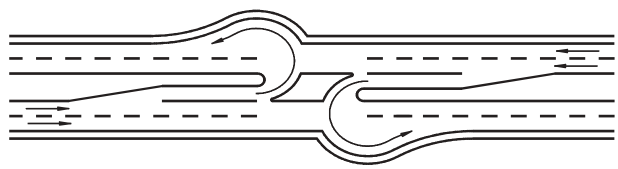
Conventional Median Opening at Four-Leg Intersection

A conventional median opening at a four-leg intersection permits vehicles on the major road to make U-turn movements on the major road and left- or right-turning movements onto the minor road. Vehicles on the minor road may make left or right turns onto the major road. No separate channelized roadways are provided for vehicles making U-turns in opposing directions. Thus, U-turn vehicles may overlap with opposing U-turn or left-turn vehicles. Median openings at four-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects. Conventional median openings are appropriate where it is desirable to allow left-turning movements from both the major road and the minor road (or driveway) and where U-turn volumes are relatively low, such that U-turn vehicles in opposing directions of travel create minimal interference with one another.

The conventional median opening design at a four-leg intersection is further classified into two subcategories based on the presence of left-turn lanes:

- Type 5a—Conventional Median Opening Without Left-Turn Lanes at Four-Leg Intersection; and
- Type 5b—Conventional Median Opening With Left-Turn Lanes at Four-Leg Intersection.

Type 2c—Directional Midblock Median Opening With Left-Turn Lanes and Loons



Advantages

- Widening on the far side of the turn makes it possible to make a U-turn without stopping or backing and reduces interference between U-turn and through traffic, particularly for large vehicles.
- Without performing major reconstruction, additional space can be provided to facilitate the larger turning path of commercial vehicles along narrow medians.
- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- This design prevents overlapping U-turns.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- The presence of loons may make snow removal and other maintenance work more difficult.

Figure 24. Advantages and disadvantages of median opening Type 2c—directional midblock median opening with left-turn lanes and loons.

Figures 31 and 32 illustrate these two median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Type 5b reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles.

Directional Median Opening for Left Turns from Major Road at Four-Leg Intersection

A directional median opening at a four-leg intersection permits vehicles to turn left off the major road onto the minor road and to make U-turn maneuvers on the major road, but does not permit vehicles to turn left from the minor road onto the major road. Median openings at four-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects. Directional median openings are appropriate where U-turn or left-turn volumes are relatively high, such that a conventional median opening would experience considerable interference between vehicles entering the median opening. This particular directional median opening design is also appropriate where there is a disproportionately high left-turn demand from the major road. Directional median openings are desirable where an intersection is going to be signalized, given that these openings only affect major-road traffic in one direction and that effective two-direction signal coordination can be maintained (*NCHRP Report 348*). This median opening design is represented in the classification as

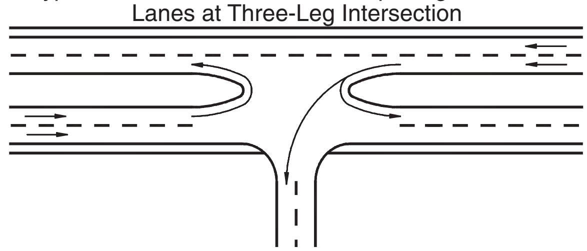
- Type 6a—Directional Median Opening for Left Turns from Major Road at Four-Leg Intersection.

Figure 33 illustrates this median opening design and its advantages and disadvantages.

Midblock Jughandles for U-Turn Maneuvers

A midblock jughandle is an indirect left-turn treatment that provides midblock access for vehicles to make a U-turn and

Type 3a—Conventional Median Opening Without Left-Turn Lanes at Three-Leg Intersection



Advantages

- Vehicles on the minor road can make both left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 11 conflict points, which is less than at a four-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where six-lane or eight-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.

Figure 25. Advantages and disadvantages of median opening type 3a—conventional median opening without left-turn lanes at three-leg intersection.

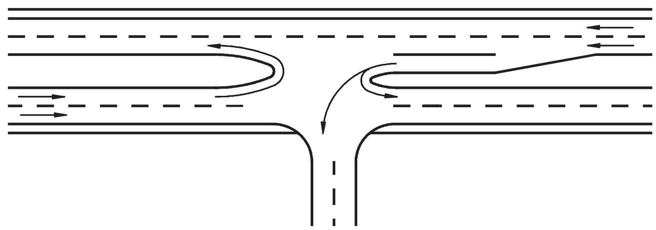
reach driveways on the opposite side of the street. Median openings at midblock locations are appropriate on arterials where providing for U-turn maneuvers between intersections may improve operations at intersections by reducing the U-turn volumes at those intersections or reducing the amount of out-of-direction travel for vehicles trying to reach a destination without direct left-turn access. Jughandles are appropriate with narrow medians, where the provision of a U-turn maneuver within the roadway cross section is not possible.

Two types of midblock jughandles have been included in the classification:

- Type 7a—Midblock Jughandle to the Left for U-turn Maneuvers; and
- Type 7b—Midblock Jughandle to the Right for U-turn Maneuvers.

In Type 7a, the U-turning vehicle begins on the inner lane of the divided highway, crosses the through-traffic lanes, loops around to the left, and then merges with the traffic. To deter vehicles from stopping on through lanes, a left-turn lane with proper storage capacity should be provided to accommodate turning vehicles. In Type 7b, the U-turning vehicle exits the major road from the outer lane, loops around to the left, stops clear of the divided highway until a suitable gap in the traffic stream develops, and then makes a normal left turn onto the divided highway.

Type 3b—Conventional Median Opening With One Left-Turn Lane at Three-Leg Intersection



Advantages

- The presence of a left-turn lane in one direction of travel reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for one direction of travel only on the major road.
- The presence of a left-turn lane in the direction of travel mitigates the problem of U-turn vehicles in that direction encroaching on the adjacent lane and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can make left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 11 conflict points, which is less than at a four-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- U-turn vehicles in the direction of travel without a left-turn lane forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- Vehicles on the major road in the direction of travel without a left-turn lane must initiate U-turn maneuvers from the through lane, which may delay through vehicles and create the potential for rear-end collisions.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-second gaps are needed to cross traffic, possibly even 10 sec where six-lane or eight-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.

Figure 26. Advantages and disadvantages of median opening type 3b—conventional median opening with one left-turn lane at three-leg intersection.

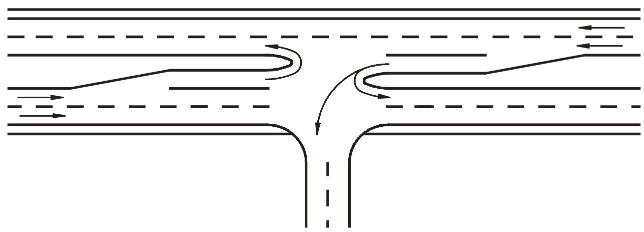
Figures 34 and 35 illustrate these two median opening designs and their advantages and disadvantages.

FACTORS THAT INFLUENCE THE SAFETY AND OPERATIONAL PERFORMANCE OF MEDIAN OPENINGS

The first part of this chapter of the report presents a classification system for median opening designs. This classification system identifies what turning movements will occur at the median opening.

Another set of factors influence how a particular median opening design will operate at a particular location. Such factors are related to the roadway environment, operational demands, physical constraints, roadway geometrics, and nearby features. Table 14 identifies the major factors that influence the safety and operational performance of median openings and constrain the choice of median openings designs.

Type 3c—Conventional Median Opening With Two Left-Turn Lanes at Three-Leg Intersection



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can make both left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 11 conflict points, which is less than at a four-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.

Figure 27. Advantages and disadvantages of median opening type 3c—conventional median opening with two left-turn lanes at three-leg intersection.

Roadway Environment

Environmental factors that influence the operational and safety performance of a median opening include degree of urbanization, speed, and access density. These three factors are interrelated to a great extent. For example, urban areas are typically characterized by lower speeds and greater access density, whereas rural areas are typically characterized by higher speeds and greater control of access.

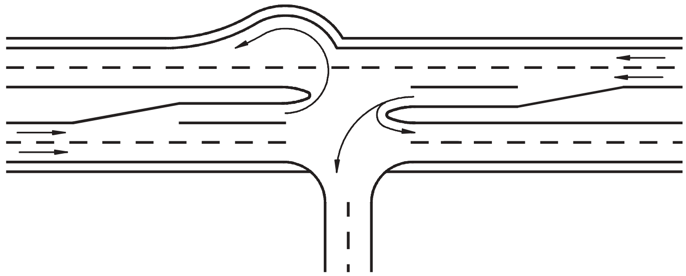
Degree of Urbanization

The type of area in which a median opening is designed (i.e., urban, suburban, or rural) also determines the traffic volumes it will experience and the turning volumes that will need to be accommodated. A median opening in an urban area probably will be surrounded by businesses that serve as traffic generators, creating a greater need for U-turns and left turns through the median opening. Median openings in rural areas, however, may only have to accommodate an occasional U-turn or left-turn vehicle because of the greater through-traffic demand of the roadway.

Operating Speed

Operating speed is another environmental factor that influences the safety and operational performance of a median

Type 3d—Conventional Median Opening With Left-Turn Lanes and Loons at Three-Leg Intersection



Advantages

- Widening on the far side of the turn makes it possible to make a U-turn without stopping or backing and reduces interference between U-turn and through traffic, particularly for large vehicles.
- Without performing major reconstruction, additional space can be provided to facilitate the larger turning path of commercial vehicles along narrow medians.
- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can make left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the cross street and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

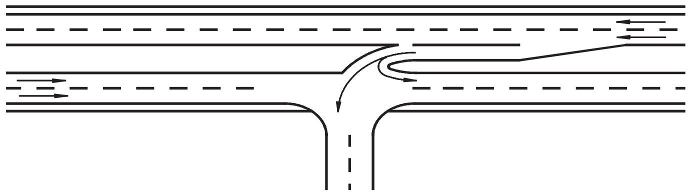
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.
- The presence of a loon may make snow removal and other maintenance work more difficult.

Figure 28. Advantages and disadvantages of median opening type 3d—conventional median opening with left-turn lanes and loons at three-leg intersection.

opening. For example, the speed of through vehicles on the major road influences left-turn lane requirements, gap availability, and weaving maneuvers.

The safety and operational performance of a median opening without a left-turn lane is largely dependent on the operating speeds of the vehicles on the roadway. Median openings, and other intersections, can experience large speed differentials between turning vehicles and following through traffic. Research has shown that accident potential increases as the difference in speeds between vehicles in a traffic stream increases. Furthermore, drivers begin to slow down a considerable distance upstream of a median opening. Thus, large speed differentials are created a considerable distance in advance of the location at which the turn is made. Left-turn

Type 4a—Directional Median Opening for Left Turns From Major Road at Three-Leg Intersection



Advantages

- The presence of a left-turn lane reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles on the major road.
- The presence of a left-turn lane mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the major road have direct left-turn access to the minor road.
- Vehicles on the major road can make left turns onto the minor road without having to accommodate minor-road vehicles making left-turn maneuvers through the median opening.
- Vehicles on the major road can make U-turn maneuvers in one direction of travel.
- Vehicles making right-turn maneuvers from the minor road do not experience delay associated with waiting behind a left-turning vehicle.
- For those maneuvers permitted, delays will be less than at a conventional median opening at a three-leg intersection.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only six conflict points, which is less than at a conventional median opening at a three-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- Minor road vehicles do not have direct left-turn access to the major road.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Additional VMT will be incurred by vehicles whose drivers desire to turn left from the minor road onto the major road.

Figure 29. Advantages and disadvantages of median opening type 4a—directional median opening for left turns from major road at three-leg intersection.

lanes are the only means of effectively controlling the speed differential between turning vehicles and other traffic on major roadways.

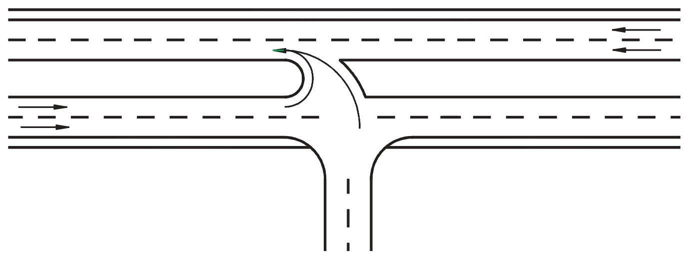
Because gaps are time based, rather than distance based, the availability of gaps for crossing and turning vehicles on a high-speed roadway is less than on a lower speed roadway with comparable traffic volumes. The reduced gap availability may cause drivers to accept smaller gaps, thus taking greater risks to perform a crossing or turning maneuver. The presence of shorter gaps can also influence the storage length requirements of any turn lanes that are present at a median opening. That is, the difficulty turning vehicles experience in completing a U-turn or left turn probably will create longer queues in a left-turn lane.

Finally, speed influences the ease with which a vehicle can perform a weaving maneuver from an upstream intersection to the median opening. Desirable conditions would permit a driver to merge into the outside lane, select an acceptable gap in order to merge into the inside lane, move laterally into the left-turn lane, and then come to a stop. The operating speeds of through vehicles on the major roadway not only affect the available gaps for merging from the outside lane to the inside lane, but determine the speed at which the weaving vehicle will enter the left-turn lane. Thus, a lower speed environment is more desirable for weaving maneuvers.

Access Density

Access density is another environmental factor that influences the safety and operational performance of a median opening. Access points introduce conflicts and friction into the traffic stream. Vehicles entering and leaving the main roadway often slow the through traffic. The differences in speeds between through and turning vehicles increase accident potential.

Type 4b—Directional Median Opening for Left Turns Onto Major Road at Three-Leg Intersection



Advantages

- Vehicles on the minor road have direct left-turn access to the major road.
- Vehicles on the major road in one direction of travel can make U-turn maneuvers.
- Right-turn maneuvers are unaffected by this treatment.
- Delays will be less than at a conventional median opening at a three-leg intersection.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only six conflict points, which is less than at a conventional median opening at a three-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- Vehicles on the major road do not have direct left-turn access to the cross street.
- The absence of a left-turn lane on the major road increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Additional VMT will be incurred by vehicles whose drivers desire to turn left from the major road onto the minor road.

Figure 30. Advantages and disadvantages of median opening type 4b—directional median opening for left turns onto major road at three-leg intersection.

Operational Demands

The number of vehicles seeking to perform each traffic movement accommodated by a median opening influences such operational and safety factors as gap availability, number of conflicts, and left-turn storage. Specifically, major-road volume, minor-road volume, left-turn volume, and U-turn volume represent operational demands that are placed on a median opening and influence its operational and safety performance. All of the volume types combined determine the number of conflicts at a median opening. That is, a median opening on a low-volume road with minimal turning volumes has fewer potential conflicts than a median opening on a high-volume roadway with large turning volumes.

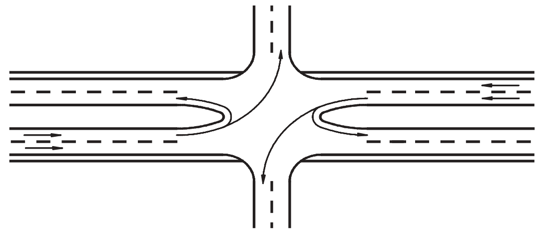
Major-Road Volume

Major-road volume plays a large role in the gap availability on the major road for vehicles performing turning and crossing maneuvers from the median opening. Large major-road volumes limit the number of gaps available for turning and crossing maneuvers and, thus, create a greater potential for angle collisions. Major-road volume also influences weaving maneuvers in advance of the median opening. In this case, large major-road volumes limit the number of gaps available for vehicles on an upstream minor-road or driveway to merge with the major-road traffic, change lanes from the outside lane to the inside lane, and safely perform a turning maneuver at the median opening. This can lead to increased potential for sideswipe collisions between weaving vehicles and through traffic.

Minor-Road Volume

Minor-road volume plays a key role in the number of crossing conflicts at a median opening. To reduce the potential for angle collisions, some median opening designs pro-

Type 5a—Conventional Median Opening Without Left-Turn Lanes at Four-Leg Intersection



Advantages

- Vehicles on the minor road can either cross the major road or make left and right turns onto the major road.
- Vehicles on the major road in both directions of travel can make left and right turns onto the minor road and make U-turns on the major road.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the cross street may experience long delays.
- There are 32 potential conflict points with both minor-road and major-road vehicles entering the median opening.
- Accident rates at four-leg intersections are higher than at three-leg intersections.

Figure 31. Advantages and disadvantages of median opening Type 5a—conventional median opening without left-turn lanes at four-leg intersection.

hibit crossing maneuvers by providing directional channelization in the median opening and restricting the minor road to right turns only.

Left-Turn and U-Turn Volumes

Left-turn volume and U-turn volume influence the safety and operational performance of a median opening. The extent of this influence is based on the presence of a median left-turn lane and its storage capacity. The absence of a left-turn lane increases the potential for rear-end collisions between U-turn or left-turn vehicles and following through vehicles. At a median opening with a left-turn lane, left-turn and U-turn volumes influence the length of the turning lane necessary to accommodate the storage requirements. A queue of vehicles extending beyond the left-turn lane interferes with through traffic and increases the potential for rear-end collisions. At any median opening, with or without a left-turn lane, left-turn volume affects the number of potential crossing conflicts between left-turn vehicles and opposing through vehicles, and U-turn volume affects the number of potential merging conflicts between U-turn vehicles and opposing through vehicles.

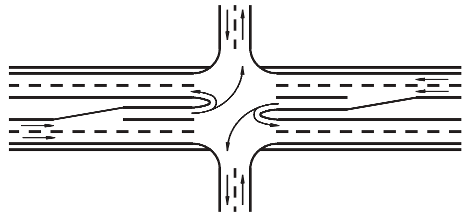
Physical Constraints

Three constraints that influence the operational and safety performance of a median opening are sight distance, right-of-way width, and building setback.

Sight Distance

Intersection sight distance (ISD) is an important safety and operational consideration in the design of a median opening.

Type 5b—Conventional Median Opening With Left-Turn Lanes at Four-Leg Intersection



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can either cross the major road or make left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the cross street may experience long delays.
- There are 32 potential conflict points with both cross-street and major-road vehicles entering the median opening.
- Accident rates at four-leg intersections are higher than at three-leg intersections.

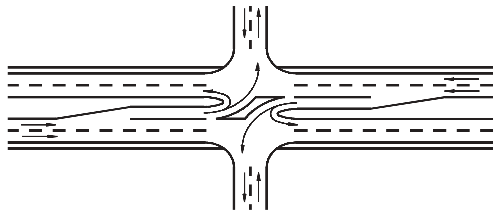
Figure 32. Advantages and disadvantages of median opening type 5b—conventional median opening with left-turn lanes at four-leg intersection.

NCHRP Report 375 states that ISD at median openings is complicated by the presence of the median itself, which may increase the ISD requirements at some locations or may contain sight obstructions that reduce the ISD. If a median is wide enough to store a vehicle, the sight distance requirements of the intersection can be determined separately for each directional roadway. Insufficient ISD has both safety and operational problems. From a safety standpoint, drivers with insufficient ISD may be unable to anticipate and avoid potential collisions. From an operational standpoint, drivers with insufficient ISD may either extend their vehicle into the traffic stream in an attempt to improve their view of the roadway or accept less than desirable gaps in the traffic stream. Either behavior may cause other vehicles to perform evasive or braking maneuvers.

Right-of-Way Width and Building Setback

Right-of-way width and building setback can limit the design options of a median opening. Local and highways agencies frequently are unable to acquire additional right-of-way because of financial or political limitations. Furthermore, the acquisition of buildings is usually avoided unless absolutely necessary. These constraints often result in a narrow median, limiting the design options to indirect left-turn designs, jughandles, or medians without a left-turn lane.

Type 6a—Directional Median Opening for Left Turn From Major Road at Four-Leg Intersection



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the major road have direct left-turn access to the minor road.
- Vehicles on the major road can make left turns onto the minor road without having to accommodate minor-road vehicles making left-turn maneuvers through the median opening.
- Vehicles on the major road in both directions of travel can make U-turn maneuvers.
- Vehicles making right-turn maneuvers from the minor road do not experience delay associated with waiting behind a left-turning vehicle.
- Delays will be less than at a conventional median opening at a four-leg intersection.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 12 conflict points, which is less than at a conventional median opening at a four-leg intersection.
- Accident rates at directional four-leg median openings are lower than at conventional four-leg median openings.

Disadvantages

- Minor-road vehicles do not have direct left-turn access to the major road.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Accident rates at four-leg intersections are higher than at three-leg intersections.
- Direct crossing maneuvers on the minor road are not permitted.
- Additional VMT will be incurred by vehicles whose drivers desire to make crossing maneuvers on the minor road and left-turn maneuvers from the minor road to the major road.

Figure 33. Advantages and disadvantages of median opening type 6a—directional median opening for left turn from major road at four-leg intersection.

Roadway Geometrics

Principal roadway geometrics that influence the operational and safety performance of a median opening are the number of lanes and the median width.

Number of Lanes

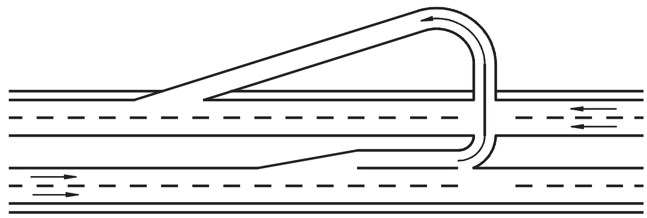
The number of lanes on an arterial affects both the safety and operational performance of a median opening. From a safety standpoint, the travel distance across opposing traffic increases for crossing and turning vehicles as the number of lanes increase. For example, a vehicle making a left turn from a six-lane arterial has a greater distance to travel across opposing traffic to complete the turn than on a four-lane arterial. Therefore, the exposure to conflicting traffic is greater.

From an operational standpoint, the number of lanes on an arterial affects the ability of vehicles to complete U-turn maneuvers and is particularly critical for U-turns on arterials with narrow medians. On a four-lane arterial, it may be necessary to provide a loon or a jughandle to accommodate U-turns. However, loons or jughandles may not be necessary on a six-lane arterial, regardless of the median width.

Median Width

Median width affects the safety and operational performance of a median opening. From a safety perspective, median widths that are either too narrow or too wide can cause various types of undesirable driving behavior that can lead to potential safety problems. *NCHRP Report 375* (*8*) reports the

Type 7a—Midblock Jughandle to the Left for U-Turn Maneuvers



Advantages

- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- There are only three conflict points, which is considerably lower than at an intersection.
- This design places vehicles in a better position for merging with major-road traffic than a conventional median opening design.
- The removal of left turns from a downstream intersection will increase the capacity of that downstream intersection.
- The presence of a left-turn lane reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of a left-turn lane mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.

Disadvantages

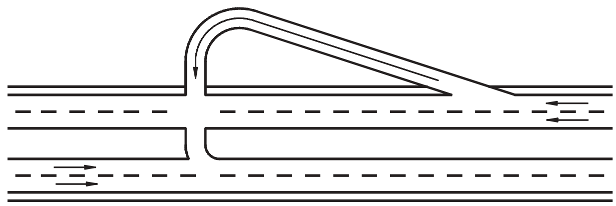
- A minimum 4.6-m (15-ft) median is required for this design.
- U-turn vehicles must make a crossing maneuver, which is not required at conventional or directional midblock median openings.

Figure 34. Advantages and disadvantages of median opening type 7a—midblock jughandle to the left for U-turn maneuvers.

following observed types of undesirable driving behavior related to median width:

- *Side-by-side queuing*—When one vehicle is waiting in the median opening for an opportunity to cross or enter the far roadway and a second vehicle arrives in the same travel direction, the second driver may stop his or her vehicle beside rather than behind the first vehicle. Side-by-side queuing is a concern because it can lead to driver confusion about which of the two vehicles is to proceed first and, thus, can lead to conflicts. This potential safety problem tends to occur where the median width is less than the length of two vehicles. Side-by-side queuing can also become a problem where a median opening is wide enough to store two or more vehicles one behind another. In this situation, the driver of a second vehicle may be tempted to pull beside the first vehicle to avoid delay. Again, this maneuver has the potential for the drivers to become confused about which vehicle is going to proceed first.
- *Angle stopping*—Another undesirable driving situation occurs when a vehicle stops on the median roadway at some angle other than perpendicular to the through lanes of the divided highway. In some cases, where the median is very narrow or a driver decides to cut a corner, the driver of a single vehicle may stop at an angle to the major road. Alternatively, when the median roadway is already occupied by one or more vehicles in the same direction of travel, a driver of another vehicle entering the median opening may find it necessary to stop at an angle to avoid encroaching on the through lanes of the major road. In either case, stopping at an unusual angle is undesirable because the vehicle may be hit by another vehicle from any of several directions and because other drivers may be confused about the intended path of that vehicle.
- *Encroachment on through lanes*—Encroachment on a through lane by either the front or rear of a vehicle may occur if the median width is less than the length of a vehicle and the driver enters the median when there is no available gap to cross or enter the far lanes of the divided highway.

Type 7b—Midblock Jughandle to the Right for U-Turn Maneuvers



Advantages

- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- The removal of left turns from a downstream intersection will increase the capacity of that downstream intersection.
- There are only three conflict points, which is considerably lower than at an intersection.

Disadvantages

- Turning traffic must cross one direction of travel and enter the roadway in the other direction of travel. Suitable gaps could be limited during periods of heavy traffic.
- During periods of heavy traffic, there could be major delays.
- The need to make a right-hand exit in order to make a U-turn may be confusing to drivers.
- The introduction of a bi-directional (although segregated) opening may increase accidents; however, this may be offset by a reduction in accidents at downstream intersections.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.

Figure 35. Advantages and disadvantages of median opening type 7b—midblock jughandle to the right for U-turn maneuvers.

TABLE 14 Factors that influence the operational and safety performance of median openings

Category	Factor
Roadway environment	degree of urbanization (urban/suburban/rural) operating speed access density
Operational demands	major-road volume minor-road volume left-turn volume U-turn volume
Physical constraints	sight distance right-of-way width building setback
Roadway geometrics	number of lanes median width
Nearby features	proximity to driveways proximity to traffic signal proximity to adjacent median openings proximity to unsignalized intersections

Nearby Features

The proximity of a median opening to the following nearby features influences the operational and safety performance of the median opening:

- Driveways,
- Adjacent median openings,
- Signalized intersections, and
- Unsignalized intersections.

NCHRP Report 420 (*7*) suggests that access points introduce conflicts and friction into the traffic stream. Vehicles entering and leaving the major road often slow the through traffic, and the difference in speeds between through and turning traffic increases accident potential. A discussion in the Green Book (*3*) about driveway spacing could also be applied to median openings and unsignalized intersections. The Green Book (*3*) recommends that, ideally, driveways should not be located within the functional area of an intersection or in the influence area of an adjacent driveway. The functional area extends both upstream and downstream from the physical intersection area and includes the longitudinal limits of auxiliary lanes. The influence area associated with a driveway includes (1) the impact length (the distance from a driveway at which vehicle operations begin to be affected), (2) the driver perception-reaction distance, and (3) the vehicle length.

A median opening placed too close to one or more driveways, intersections, or other median openings creates undesirably short weaving areas. For example, minor-road drivers seeking to negotiate their way to a nearby median opening on the major road should be able to enter the major-road traffic stream safely, select an acceptable gap in order to merge into the inside lane, and then move laterally into a median left-turn lane.

The following are safety and operational problems that may occur when a median opening is located too close to a signalized intersection:

- A median opening within the physical length of a left-turn bay should be avoided. It violates driver expectancy and restricts the sight distance of vehicles in the median opening.
- A median opening within the boundaries of regularly forming queues from neighboring intersections should be avoided. The problem with this situation is that when these queues build, "good Samaritans" may allow the left-turning vehicle through the queue, and the left-turning vehicle then crashes with a vehicle moving freely in an adjacent lane.
- When the queue in the through traffic lane extends past the median left-turn lane, vehicles seeking access to the median opening are trapped in the queue of the signalized intersection and cannot move into the left-turn lane until the queue advances.

RELATIVE SAFETY OF MEDIAN OPENING DESIGNS BASED ON TRAFFIC CONFLICT POINTS

The classification of median opening designs provides a framework for comparing the relative safety of each design. The results of the accident data analysis, presented in Chapter 6 of this report, provide information on the relative safety performance of those median opening designs for which sufficient data existed. However, data for several median opening designs were not sufficient to quantify the relative safety with certainty. In these cases, the relative safety of each median opening design must be estimated or hypothesized. The relative safety of median opening designs can be represented by the number of conflict points for each design. This approach is useful in the absence of actual data, but is ultimately limited because it does not consider the volumes of vehicles that conflict at each point. The use of conflict points to assess safety is described below.

Intersection conflict analysis is a well-understood means of addressing the complexity and relative safety of alternative intersection designs. For example, it has long been known that three-leg intersections operate more safely than four-leg intersections because three-leg intersections have fewer conflict points at which conflicting traffic streams cross, merge, or diverge. Figure 36 illustrates the four basic types of vehicular conflicts: diverging, merging, weaving, and crossing.

Intersection conflicts reflect the crossing or conflicting paths of vehicles moving from one leg to another. Depending on the type of movement (i.e., U-turn, right or left turn, or crossing), any given vehicle movement can conflict with one or more other vehicle movements.

Figure 37 illustrates the vehicular conflicts at a conventional median opening at a four-leg intersection. The figure includes left-turn, right-turn, and through movements, but does not explicitly consider U-turn movements. However, any given U-turn movement includes the same diverge maneuver as one left-turn movement and the same merge maneuver as another left-turn movement.

Table 15 summarizes the total number of conflict points for each of the typical median opening designs discussed earlier in Chapter 4 of the report. Table 15 suggests that median

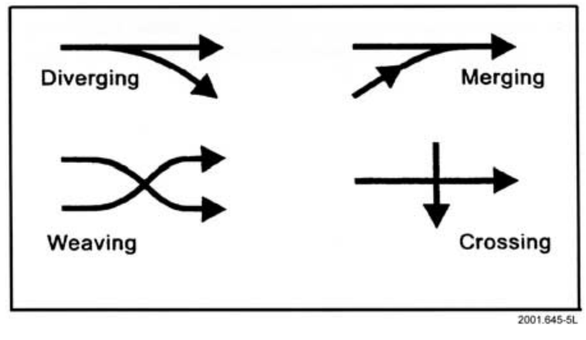


Figure 36. Types of vehicular conflicts (33).

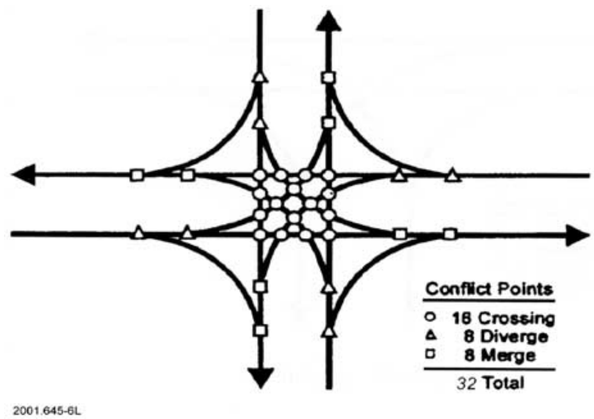


Figure 37. Vehicular conflicts at a conventional median opening at a four-leg intersection (27, 33).

opening designs should rank in the following order of relative safety:

Midblock Median Openings

- 7—Midblock Jughandle
- 1—Conventional Midblock Median Opening
- 2—Directional Midblock Median Opening

Median Openings at Three-Leg Intersections

- 4—Directional Median Opening at Three-Leg Intersection
- 3—Conventional Median Opening at Three-Leg Intersection

Median Openings at Four-Leg Intersections

- 6—Directional Median Opening at Four-Leg Intersection
- 5—Conventional Median Opening at Four-Leg Intersection

COMBINATIONS OF MEDIAN OPENINGS ALONG ARTERIAL STREETS

Earlier in this chapter, seven categories of typical median openings were presented, along with subcategories based on the presence of left-turn lanes or loons or type of turning maneuvers permitted. Each type of typical median opening design represents one individual median opening. Often, highway agencies use combinations of median opening designs to accomplish a particular goal along an arterial.

This section presents several typical combinations of median opening designs that can be used along an arterial. Each combination is presented as a sum of the individual typical median opening designs that make up the combination. For example, the first combination (Combination C1) is a directional midblock median opening with left-turn lanes (Type 2b) between two four-leg intersections with directional median openings that accommodate left turns from the major road (Type 6a). Thus, this combination is represented as:

Combination C1 = Type 6a + Type 2b + Type 6a

Eight typical combinations of median opening designs are presented below; many other combinations are possible. Chapter 6 of this report presents two examples of a safety comparison between an individual median opening and a combination of median openings accommodating the same turning movements.

Combination C1—Directional Midblock Median Opening Between Four-Leg Intersections With Directional Median Openings

Combination C1 consists of a directional midblock median opening with left-turn lanes located between two four-leg intersections with left-turn lanes and directional median openings

TABLE 15 Total number of conflict points for each typical median opening design

	Typical median opening design	Number of conflict points
1.	Conventional Midblock Median Opening	4
2.	Directional Midblock Median Opening	4
3.	Conventional Median Opening at Three-Leg Intersection	11
4.	Directional Median Opening at Three-Leg Intersection	6
5.	Conventional Median Opening at Four-Leg Intersection	32
6.	Directional Median Opening at Four-Leg Intersection	12
7.	Midblock Jughandle	3

that accommodate U-turns and left turns from the major road, but not left turns from the minor road. This combination is illustrated in Figure 38 and is represented as

Combination C1 = Type 6a + Type 2b + Type 6a

Combination C1 can be used as an alternative to direct left turns in order to reduce conflicts and to improve safety along an arterial. Midblock U-turns make it possible to prohibit left turns from the minor road at each four-leg intersection and from driveways along the arterial. Vehicles must make left-turn movements by turning right onto the arterial and then making U-turns downstream. This combination is appropriate where left-turn demand on the minor road is relatively low or where it is desirable to reduce U-turn demand at the downstream intersection.

Combination C2—Conventional Midblock Median Opening Between Four-Leg Intersections With Conventional Median Openings

Combination C2 is a conventional midblock median opening with left-turn lanes located between two four-leg intersections with left-turn lanes and conventional median openings. This combination is illustrated in Figure 39 and is represented as:

Combination C2 = Type 5b + Type 1b + Type 5b

Combination C2 provides access to through vehicles on the major road to development on the opposite side of the median. This combination is appropriate where left-turn demand on the minor road is relatively high or where it is desirable to reduce U-turn demand at the downstream intersection.

Combination C3—Directional Midblock Median Opening Between Four-Leg Intersections With Conventional Median Openings

Combination C3 includes a directional midblock median opening with left-turn lanes located between two four-leg intersections with left-turn lanes and conventional median openings. This combination is illustrated in Figure 40 and is represented as

Combination C3 = Type 5b + Type 2b + Type 5b

Combination C3 provides access to through vehicles on the major road to development on the opposite side of the median. The directional midblock median opening can accommodate heavy U-turn volumes. This combination is appropriate where left-turn demand on the minor road is relatively light or where it is desirable to reduce U-turn demand at the downstream intersection.

Combination C4—Directional Midblock Median Opening Between Four-Leg Intersections Without Median Openings

Combination C4 is a directional midblock median opening with left-turn lanes located between two four-leg intersections without median openings. This combination is illustrated in Figure 41 and is represented as

Combination C4 = Closed Type 5a + Type 2b
+ Closed Type 5a

Combination C4 can be used as an alternative to direct left turns in order to reduce conflicts and to improve safety along an arterial. Midblock U-turns make it possible to close the median opening at each four-leg intersection and prohibit

Combination C1 = Type 6a + Type 2b + Type 6a

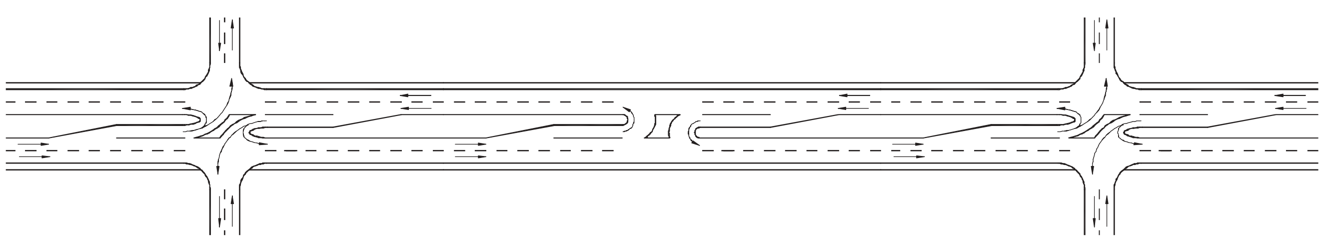


Figure 38. Combination C1—directional midblock median opening between four-leg intersections with directional median openings.

Combination C2 = Type 5b + Type 1b + Type 5b

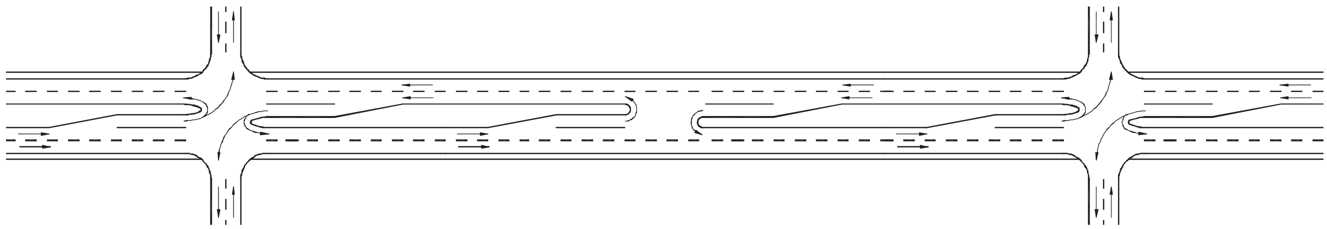


Figure 39. Combination C2—Conventional midblock median opening between four-leg intersections with conventional median openings.

Combination C3 = Type 5b + Type 2b + Type 5b

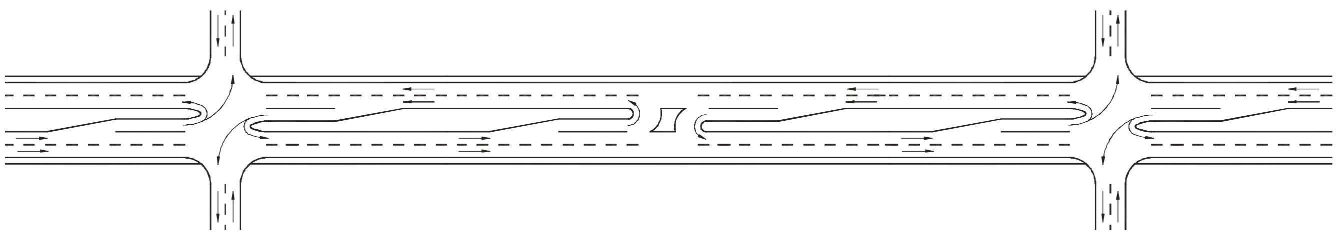


Figure 40. Combination C3—Directional midblock median opening between four-leg intersections with conventional median openings.

Combination C4 = Closed Type 5a + Type 2b + Closed Type 5a

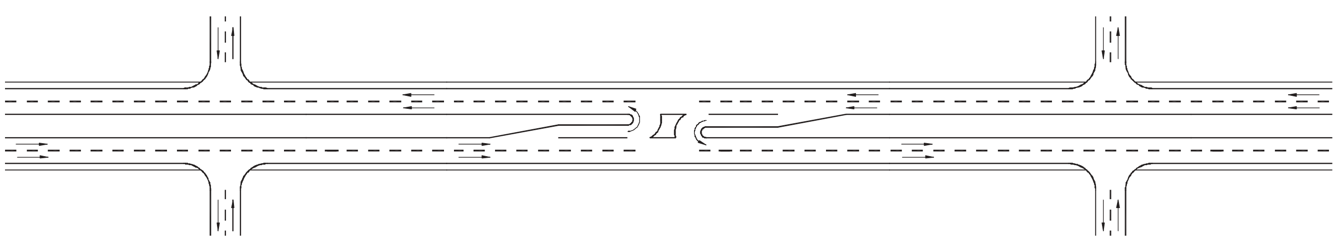


Figure 41. Combination C4—directional midblock median opening between four-leg intersections without median openings.

left-turn movements from driveways along the arterial. Vehicles must make left-turn or crossing movements by turning right onto the arterial and then making U-turns downstream. The directional midblock median opening can accommodate heavy U-turn volumes. This combination is appropriate where conventional median openings at four-leg intersections are experiencing safety problems such that the most effective treatment is to close the median openings.

Combination C5—Directional Midblock Median Opening Between Three-Leg Intersections Without Median Openings

Combination C5 includes a directional midblock median opening with left-turn lanes located between two three-leg intersections without median openings. This combination is illustrated in Figure 42 and is represented as

Combination C5 = Closed Type 3a + Type 2b
+ Closed Type 3a

Combination C5 can be used as an alternative to direct left turns in order to reduce conflicts and to improve safety along an arterial. Midblock U-turns make it possible to close the median opening at each three-leg intersection and prohibit left-turn movements from driveways along the arterial. Vehicles must make left-turn movements by turning right onto the arterial and then making U-turns downstream. The directional midblock median opening can accommodate heavy U-turn volumes. This combination is appropriate where conventional median openings at three-leg intersections are experiencing safety problems such that the most effective treatment is to close the median openings.

Combination C6—Conventional Midblock Median Opening Between Four-Leg Intersections Without Median Openings

Combination C6 includes a conventional midblock median opening with left-turn lanes between two four-leg intersections without median openings. This combination is illustrated in Figure 43 and is represented as

Combination C6 = Closed Type 5a + Type 1b
+ Closed Type 5a

Combination C6 is similar to Combination C4, except that Combination C6 has a conventional rather than a directional midblock median opening. Combination C6 serves the same purposes as Combination C4, but is more appropriate where U-turn volumes are relatively light.

Combination C7—Conventional Midblock Median Opening Between Three-Leg Intersections Without Median Openings

Combination C7 consists of a conventional midblock median opening with left-turn lanes between two three-leg intersections without median openings. This combination is illustrated in Figure 44 and is represented as

Combination C7 = Closed Type 3a + Type 1b
+ Closed Type 3a

Combination C7 is similar to Combination C5, except that Combination C7 has a conventional rather than a directional midblock median opening. Combination C7 serves the same purposes as Combination C5, but is more appropriate where U-turn volumes are relatively light.

Combination C8—Directional Midblock Median Opening Between Four-Leg Signalized Intersections With Conventional Median Openings But All Left-Turning Movements Prohibited

Combination C8 includes a directional midblock median opening with left-turn lanes between two signalized four-leg intersections with conventional median openings, no left-turn

Combination C5 = Closed Type 3a + Type 2b + Closed Type 3a

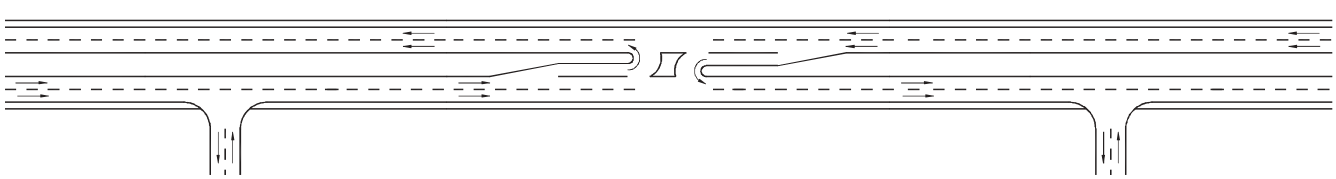


Figure 42. Combination C5—directional midblock median opening between three-leg intersections without median openings.

Combination C6 = Closed Type 5a + Type 1b + Closed Type 5a

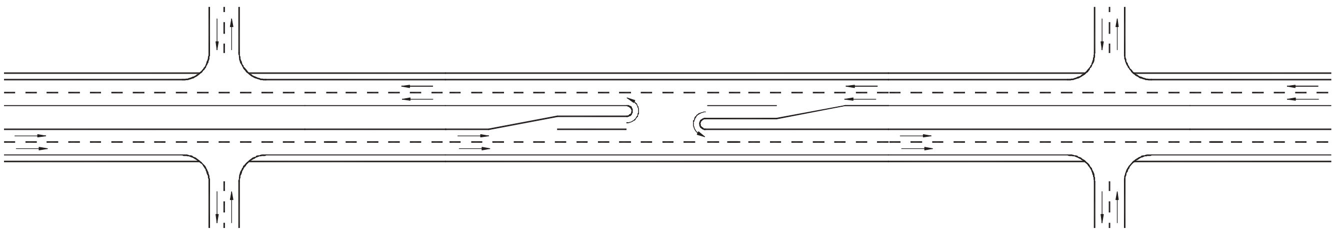


Figure 43. Combination C6—conventional midblock median opening between four-leg intersections without median openings.

Combination C7 = Closed Type 3a + Type 1b + Closed Type 3a

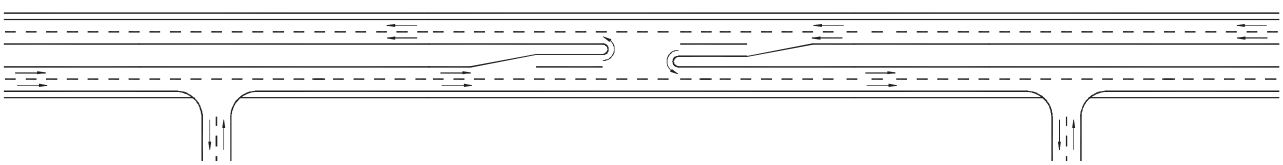


Figure 44. Combination C7—conventional midblock median opening between three-leg intersections without median openings.

Combination C8 = Signalized Type 5a + Type 2b + Signalized Type 5a

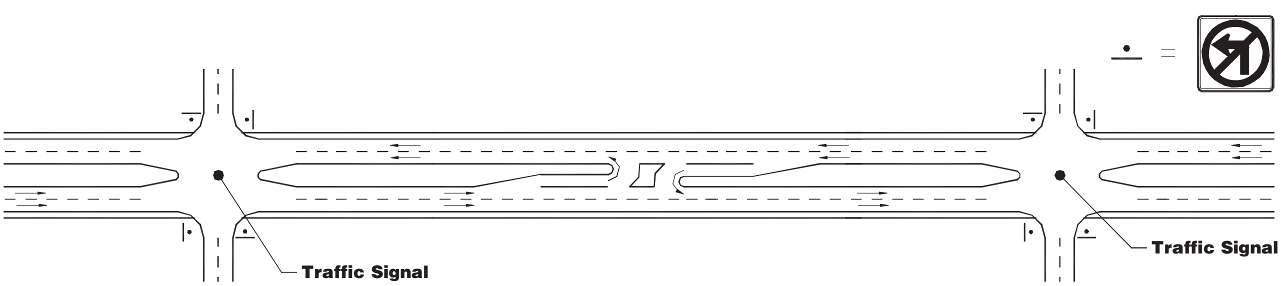


Figure 45. Combination C8—directional midblock median opening between four-leg signalized intersections with conventional median openings but all left-turning movements prohibited.

lanes, and all left-turning movements prohibited. This combination is illustrated in Figure 45 and is represented as

Combination C8 = Signalized Type 5a + Type 2b
+ Signalized Type 5a

Combination C8 can be used as an alternative to direct left turns in order to reduce conflicts and improve safety along an arterial and to simplify signal phasing at signalized intersections. Midblock U-turns make it possible to prohibit all left turns at the signalized intersections as well as prohibit left turns from driveways along the arterial. Minor-road vehicles must make left-turn movements by turning right onto the arterial and then making U-turns downstream. Major-road vehicles must make left-turn or U-turn movements by proceeding through the intersection, making U-turns at the midblock median opening, and turning right onto the minor road. This combination is appropriate where conventional median openings at signalized four-leg intersections are experiencing safety problems such that the most effective treatment is to reduce the number of conflicts by prohibiting turning movements at the intersections. It is generally considered good practice to provide right-turn lanes on all approaches to the signalized intersection to accommodate the heavy right-turn volumes that are inherent to indirect left-turn intersections.

CHAPTER 5

DATA COLLECTION AND ANALYSIS

This chapter describes the data collection and analysis efforts conducted as part of the research. The major efforts were a catalog of existing median openings, accident studies of existing median openings, field observational studies of existing median openings, and human factors evaluation of driver behavior in U-turn maneuvers.

CATALOG OF EXISTING MEDIAN OPENINGS

The first activity of the data collection effort was to create a catalog of median opening designs representative of what actually exists in the field. The first task in the creation of a catalog was to identify arterial corridors that include median openings. The second task was visiting the corridors and collecting data on the types of median opening designs. This section describes the process of creating a catalog of existing median openings and summarizes the catalog data.

Identification of Corridors

To identify corridors, the research team contacted highway engineers in five states and requested a list of arterial corridors that include median opening designs representative of that state. The states contacted were as follows:

- Colorado,
- Georgia,
- Michigan,
- New Jersey, and
- New York.

A list of approximately 10 to 20 corridors of varying lengths was obtained from each state. In Georgia, all of the corridors were located in Gwinnett County and are under the jurisdiction of that county. In the other states, the corridors were under the jurisdiction of the state highway agency and were located in several counties in each state. The research team also identified, through personal experience and the use of state highway maps, corridors within the states of Kansas and Missouri. Overall, corridors were identified in seven states throughout the country for collection of detailed information for cataloging purposes.

Collection of Catalog Data

Each corridor was visited in the field to collect the following information on individual median openings:

- Location of median opening (milepost or odometer reading),
- Cross street name,
- Type of traffic control,
- Type of median opening,
- U-turn prohibition,
- Area type (urban/suburban),
- Posted speed limit,
- Number of through lanes,
- Presence of left-turn lanes,
- Presence of offset left-turn lanes,
- Shoulder type,
- Median type,
- Median width,
- Presence of loon, and
- Level of U-turn activity.

For each unsignalized median opening, the median opening type was classified according to the categories established in Chapter 4 of this report.

Summary of Catalog Data

This section presents a detailed summary of the unsignalized median openings included in the catalog. Specifically, the distribution of unsignalized median openings by state, median opening type, posted speed limit, number of through lanes, presence of special left-turn treatment, shoulder type, median width and type, and level of U-turn activity are presented.

The catalog consisted of 62 arterial corridors in seven states. The corridors comprised a total length of 552 km (343 mi) of arterial highway, or an average of 8.9 km (5.5 mi) per corridor. Data were recorded for 918 unsignalized median openings located in the 62 arterial corridors. Not all sites, however, were included in the tables presented below. For example, 14 of the unsignalized median openings did not fit into any of the median opening types as outlined in Chapter 4. Also, U-turns were prohibited at 102 of the unsignalized median openings; given that U-turn maneuvers are the focus of the research, those median openings were not included in the tables presented below. Finally, four median openings had five-lane cross-sections (i.e., three through lanes in one direction of travel and two in the other). Given that the focus of the accident and field studies was on unsignalized median openings on four-lane and six-lane cross-sections, the four five-lane sites were not included in the tables presented below. Thus, 806 unsignalized median openings are included in the tables.

State

Table 16 lists the number of unsignalized median openings visited in each state. The distribution of sites by state provided a good geographical diversity for accident and field studies.

Median Opening Type

Based on the classification of median opening types presented in Chapter 4, there are a total of 17 typical median opening design as follows:

- 1a = Conventional midblock median opening without left-turn lanes
- 1b = Conventional midblock median opening with left-turn lanes
- 1c = Conventional midblock median opening with left-turn lanes and loons
- 2a = Directional midblock median opening without left-turn lanes
- 2b = Directional midblock median opening with left-turn lanes
- 2c = Directional midblock median opening with left-turn lanes and loons
- 3a = Conventional median opening without left-turn lanes at three-leg intersection
- 3b = Conventional median opening with one left-turn lane at three-leg intersection
- 3c = Conventional median opening with two left-turn lanes at three-leg intersection
- 3d = Conventional median opening with left-turn lanes and loons at three-leg intersection
- 4a = Directional median opening for left turns from major road at three-leg intersection
- 4b = Directional median opening for left turns onto major road at three-leg intersection
- 5a = Conventional median opening without left-turn lanes at four-leg intersection
- 5b = Conventional median opening with left-turn lanes at four-leg intersection
- 6a = Directional median opening for left turns from major road at four-leg intersection
- 7a = Midblock jughandle to the left for U-turn maneuvers
- 7b = Midblock jughandle to the right for U-turn maneuvers

Table 17 presents the frequency of unsignalized median openings by median opening type. Table 18 presents the number of unsignalized median openings by state and median opening type.

Posted Speed Limit

Table 19 presents the distribution of sites by posted speed limit and median opening type. The table illustrates a balance between high-speed and low-speed arterials overall, with 43 percent of all median openings located on low-speed arterials and 57 percent located on high-speed arterials.

TABLE 16 Number of unsignalized median openings by state

State	Number of median openings	(%)
Colorado	61	(8)
Georgia	150	(19)
Kansas	137	(17)
Michigan	244	(30)
Missouri	111	(14)
New Jersey	62	(8)
New York	41	(5)
Total	806	

TABLE 17 Number of unsignalized median openings by median opening type

Median opening type	Number of median openings	(%)
Midblock		
1a	40	(5.0)
1b	22	(2.7)
1c	6	(0.7)
2a	1	(0.1)
2b	149	(18.5)
2c	17	(2.1)
Three-leg		
3a	102	(12.7)
3b	91	(11.3)
3c	78	(9.7)
3d	9	(1.1)
4a	24	(3.0)
4b	0	(0.0)
Four-leg		
5a	94	(11.7)
5b	159	(19.7)
6a	14	(1.7)
Jughandle		
7a	0	(0.0)
7b	0	(0.0)
Total	806	(100.0)

TABLE 18 Number of unsignalized median openings by state and median opening type

Median opening type	State							Total
	CO	GA	KS	MI	MO	NJ	NY	
Midblock								
1a			14 (10.2)	2 (0.8)	3 (2.7)	19 (30.6)	2 (4.9)	40
1b	1 (1.6)	15 (10.0)		6 (2.5)				22
1c		5 (3.3)	1 (0.7)					6
2a						1 (1.6)		1
2b				146 (59.8)		1 (1.6)	2 (4.9)	149
2c				12 (4.9)			5 (12.2)	17
Three-leg								
3a			43 (31.4)	14 (5.7)	27 (24.3)	15 (24.2)	3 (7.3)	102
3b	20 (32.8)	12 (8.0)	15 (10.9)	15 (6.1)	11 (9.9)	15 (24.2)	3 (7.3)	91
3c	1 (1.6)	52 (34.7)	2 (1.5)	17 (7.0)	2 (1.8)	1 (1.6)	3 (7.3)	78
3d		9 (6.0)						9
4a	7 (11.5)	4 (2.7)	2 (1.5)	7 (2.9)	1 (0.9)	1 (1.6)	2 (4.9)	24
Four-leg								
5a			26 (19.0)	17 (7.0)	43 (38.7)	5 (8.1)	3 (7.3)	94
5b	30 (49.2)	53 (35.3)	29 (21.2)	8 (3.3)	23 (20.7)	4 (6.5)	12 (29.3)	159
6a	2 (3.3)		5 (3.6)		1 (0.9)		6 (14.6)	14
Total	61	150	137	244	111	62	41	806

NOTE: Numbers in parentheses are column percentages.

Cross-Section

Table 20 presents the distribution of sites by cross section and median opening type. Most of the arterial corridors recommended to the research team by highway agencies were four-lane arterials; about 10 percent of the sites are located on six-lane arterials.

Special Left-Turn Treatments

When conducting the site visits, the research team members noted the presence of offset left-turn lanes, loons, and dual left-turn lanes. These special left-turn treatments will be considered in the accident and field studies because they can influence the safety of an unsignalized median opening. Offset left-turn lanes provide improved sight distance; loons provide extra pavement width for U-turn vehicles with a large turning radius; and dual left-turn lanes can be confusing to some drivers. Of the 806 unsignalized median openings, 79 had offset left-turn lanes, 34 had loons, and 3 had dual left-turn lanes.

Shoulder Type

The type of shoulder provided at each of the unsignalized median openings was noted during the site visits. Table 21 presents the distribution of sites by shoulder type. Most of the median openings had paved shoulders.

TABLE 19 Number of median openings by posted speed limit and median opening type

Median opening type	Posted speed limit	
	Low speed (≤ 50 mph)	High speed (≥ 55 mph)
Midblock		
1a	3 (0.9)	37 (8.0)
1b	8 (2.3)	14 (3.0)
1c	3 (0.9)	3 (0.7)
2a	0 (0.0)	1 (0.2)
2b	26 (7.5)	123 (26.7)
2c	8 (2.3)	9 (2.0)
Three-leg		
3a	23 (6.6)	79 (17.2)
3b	69 (19.9)	22 (4.8)
3c	38 (11.0)	40 (8.7)
3d	9 (2.6)	0 (0.0)
4a	23 (6.6)	1 (0.2)
Four-leg		
5a	20 (5.8)	74 (16.1)
5b	105 (30.3)	54 (11.7)
6a	11 (3.2)	3 (0.7)
Total	346	460

TABLE 20 Number of median openings by cross section and median opening type

Median opening type	Major-road cross-section	
	4-lane	6-lane
Midblock		
1a	40 (5.5)	0 (0.0)
1b	21 (2.9)	1 (1.2)
1c	6 (0.8)	0 (0.0)
2a	1 (0.1)	0 (0.0)
2b	140 (19.4)	9 (10.6)
2c	12 (1.7)	5 (5.9)
Three-leg		
3a	102 (14.1)	0 (0.0)
3b	77 (10.7)	14 (16.5)
3c	68 (9.4)	10 (11.8)
3d	9 (1.2)	0 (0.0)
4a	7 (1.0)	17 (20.0)
Four-leg		
5a	94 (13.0)	0 (0.0)
5b	134 (18.6)	25 (29.4)
6a	10 (1.4)	4 (4.7)
Total	721	85

TABLE 21 Number of median openings by shoulder type

Shoulder type	Number of sites	
Paved	480	(59.8)
Curb	244	(30.3)
Mountable curb	21	(2.6)
Other	56	(6.9)
No shoulder	5	(0.6)
Total	806	

Median Type and Width

The type and width of median at each of the unsignalized median openings was noted during the site visits. Of the 806 unsignalized median openings, 502 median openings (62 percent) were located at raised medians, 303 median openings (38 percent) were located at depressed medians, and one median opening was located at a paved median. About one-third of the median openings were 6 m (20 ft) wide or less; about one-third were between 6 and 12 m (20 and 40 ft) wide; and about one-third were greater than 12 m (40 ft) wide.

U-Turn Potential

At each unsignalized median opening, research team members estimated the potential for U-turn activity at that site, based on the surrounding development or actual U-turn activity observed. Table 22 presents the distribution of U-turn potential by median opening type.

TABLE 22 Number of median openings by U-turn potential and median opening type

Median opening type	U-turn potential			
	Low		High	
Midblock				
1a	21	(4.6)	19	(5.4)
1b	13	(2.9)	9	(2.6)
1c	2	(0.4)	4	(1.1)
2a	0	(0.0)	1	(0.3)
2b	2	(0.4)	147	(41.8)
2c	1	(0.2)	16	(4.5)
Three-leg				
3a	79	(17.4)	23	(6.5)
3b	64	(14.1)	27	(7.7)
3c	54	(11.9)	24	(6.8)
3d	2	(0.4)	7	(2.0)
4a	12	(2.6)	12	(3.4)
Four-leg				
5a	76	(16.7)	18	(5.1)
5b	120	(26.4)	39	(11.1)
6a	8	(1.8)	6	(1.7)
Total	454		352	

Median Opening Types Included in Data Collection and Analysis

Based on the catalog of median opening designs that are representative of what actually exists in the field, the following median opening designs were given highest priority in the accident and field studies:

- Type 1a = Conventional midblock median opening without left-turn lanes
- Type 1b = Conventional midblock median opening with left-turn lanes
- Type 2b = Directional midblock median opening with left-turn lanes
- Type 2c = Directional midblock median opening with left-turn lanes and loons
- Type 3a = Conventional median opening without left-turn lanes at three-leg intersection
- Type 3b = Conventional median opening with one left-turn lane at three-leg intersection
- Type 3c = Conventional median opening with two left-turn lanes at three-leg intersection
- Type 4a = Directional median opening for left turns from major road at three-leg intersection
- Type 5a = Conventional median opening without left-turn lanes at four-leg intersection
- Type 5b = Conventional median opening with left-turn lanes at four-leg intersection
- Type 6a = Directional median opening for left turns from major road at four-leg intersection

These median opening designs appeared to be most commonly used by highway agencies and/or were most promising in terms of safety performance. The preceding list includes median opening Type 2c, directional midblock median opening with left-turn lanes and loons. The usage of loons was observed in four of the states visited in the catalog process (i.e., Georgia, Kansas, Michigan, and New York). Therefore, they were included in the accident and field studies to assess their appropriateness for wider use.

DATA COLLECTION AND ANALYSIS FOR SELECTED MEDIAN OPENINGS

Three major data collection and analysis activities were conducted in the research:

- Field observational studies of existing median openings used for U-turns,
- Accident studies of existing median openings used for U-turns, and
- Analysis of traffic conflicts and driver behavior at median openings used for U-turns.

The following discussion provides an overview of each of these data collection and analysis efforts. The findings of those analyses are presented in Chapter 6.

Field Observational Studies of Existing Median Openings

Field observational studies were conducted at four corridors in each of the following five geographic regions, for a total of 20 corridors:

- West (Colorado),
- Midwest (Kansas/Missouri),
- North (Michigan),
- South (Georgia), and
- Northeast (New Jersey/New York).

The corridors were selected on the basis of median opening types and level of U-turn activity. Within each corridor, one intersection was selected for videotaping on the basis of the data already collected during the catalog process and a further field review of the site. The intersections selected for videotaping were selected to cover the range of median opening types and median widths of interest to the study.

The field observational studies involved videotaping one unsignalized median opening in each arterial corridor for periods of approximately 6 hours per site, including the evening peak period and two off-peak periods. Table 23 presents the number of videotaped median openings in each geographic region by median opening type.

The videotapes were used for two purposes: (1) to obtain counts of turning movement volumes at the intersections and (2) to note traffic conflicts and undesirable driving behavior that may be indicators of safety problems at the median opening. From the turning movement counts, typical U-turn volumes (and percentage of total turning volumes) for median openings with various designs were determined. Data on traffic conflicts and undesirable driving behavior were used in the human factors evaluation.

Figure 46 illustrates the field setup used in the study, with video cameras in two different quadrants of the intersection. This setup provided good viewing angles for all turning movements at the intersection and allowed any traffic conflicts or undesirable driving behavior to be reviewed and classified from more than one angle. The quadrants chosen for camera locations varied from site to site to obtain the best viewing angles. The video cameras were equipped with character generators with the capability of superimposing an elapsed time to the nearest 0.1 sec on the recorded video image to document the precise time at which events of interest occurred.

In addition to the one field observational study per corridor, short 15- to 30-min turning movement counts were performed at other median openings in the corridor during the same period as the video studies. These counts were scaled up to the full period of the video study using the traffic count data from the videotapes for the primary study site in the same corridor. These additional volume counts (including U-turn volumes) allowed for better use of the accident data for those other median openings. Table 24 presents the number of median openings, by median opening type and geographic region, at which turning movement counts were obtained, either from the videotapes or from supplemental manual counts.

To supplement the information on individual median openings obtained during the catalog process, the following site characteristics were documented during the field observational studies:

- Median opening dimensions (i.e., length and width),
- Distance to nearest intersection,
- Distance to nearest signal,
- Distance to nearest driveway,
- Character of surrounding development, and
- Level of pedestrian activity.

Documentation obtained in the field included photographs of specific median opening types.

Accident Studies of Existing Median Openings

Accident data, including data on the characteristics of each individual traffic accident at or related to the median openings of interest, were obtained from the participating highway agencies. Then, accident studies of existing median openings were conducted to learn the following:

TABLE 23 Number of videotaped median openings (by median opening type) in each geographic region

Geographic region	Median opening type											Total
	1a	1b	2b	2c	3a	3b	3c	4a	5a	5b	6a	
West (CO)	–	–	–	–	–	1	–	1	–	2	–	4
Midwest (KS/MO)	1	–	–	–	1	2	–	–	2	1	–	7
North (MI)	–	–	8	4	–	–	–	–	–	–	–	12
South (GA)	–	–	–	–	–	–	1	–	–	1	–	2
Northeast (NJ/NY)	–	–	–	1	–	2	–	2	–	1	1	7
Total	1	–	8	5	1	5	1	3	2	5	1	32

NOTE: Michigan sample sizes are larger than other states because the study sites were pairs of directional median openings rather than single bidirectional median openings.

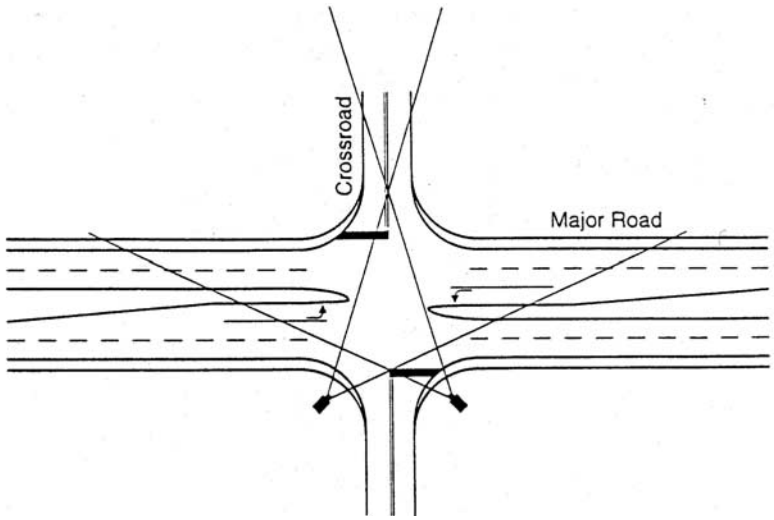


Figure 46. Typical data collection setup using video cameras (8).

- Traffic accident frequencies and rates for median openings of various types,
- Relationship of U-turn volumes to median opening accident rates, and
- Pattern of accident types and severities at median openings with substantial U-turn volumes and at median openings with relatively few U-turns.

Accident Data

Accident data were obtained from each of the participating highway agencies for the selected corridors for a period of at least 4 years. The periods for which accident data were obtained for median opening sites in each state were as follows:

- Colorado (1997–2001)
- Georgia (1997–2001)
- Kansas (1997–2001)
- Michigan (1993–1997)
- Missouri (1997–2001)
- New Jersey (1997–2000)
- New York (1996–2001)

Complete accident data were not available for every study corridor. A few of the corridors were not state-maintained and, therefore, the accident data for some of these corridors were either unavailable or were incomplete. The accident descriptors that were obtained are as follows:

- Accident location (milepost or other information that identifies the location of accidents with respect to the median openings of interest),
- Relationship to junction (at intersection/not at intersection, but intersection related),
- Accident date,
- Time of day,
- Accident severity,
- Light condition (day and night),
- Pavement surface condition (i.e., dry/wet/ice and snow),
- Accident type/manner of collision,
- Initial direction of travel of involved vehicles,
- Intended maneuvers of involved vehicles (i.e., straight ahead/right turn/left turn/U-turn),
- Vehicle types of involved vehicles (e.g., passenger car/bus/truck/RV), and
- First harmful event/most harmful event.

TABLE 24 Number of median openings (by median opening type) in each geographic region at which turning movement counts were obtained

Geographic region	Median opening type											Total
	1a	1b	2b	2c	3a	3b	3c	4a	5a	5b	6a	
West (CO)	–	–	–	–	–	7	–	5	–	10	1	23
Midwest (KS/MO)	1	–	–	–	2	2	–	–	5	3	–	13
North (MI)	–	–	21	10	1	–	–	–	–	–	–	32
South (GA)	–	1	–	–	–	12	1	1	–	12	–	27
Northeast (NJ/NY)	1	–	1	4	–	9	1	3	–	6	5	30
Total	2	1	22	14	3	30	2	9	5	31	6	125

For median openings at intersections, the project database includes all accidents identified by the investigating officer or by data coding as related to that intersection. For intersections not at median openings, all accidents within 75 m (250 ft) of the median opening are included in the database. Where accident locations could not be tied accurately to a specific median opening (which occurred at midblock locations for some agencies), that particular median opening was dropped from the project database.

Traffic Volume Data

Traffic volume data and turning movement counts, where available, were obtained from the files of the participating agencies. Where traffic volume data were not available for a set of median openings in a corridor, the research team (1) performed turning movement counts (including counts of U-turn maneuvers) for at least one median opening in the corridor and (2) estimated the traffic volumes for the other median openings in the corridor based on observations of the general level of turning activity (i.e., high, medium, and low) and comparison of the relative access point densities of the median openings whose U-turn volumes are known and those whose U-turn volumes are not known.

Accident Distributions

Out of a total of 7,717 median-opening-related accidents, only 79 accidents (1.1%) were identified as involving U-turns. Because this did not appear to be a sufficient number of U-turn accidents to draw useful conclusions about the safety performance of median openings, a decision was made to include both U-turn and left-turn accidents in the analyses. Review of the accident data indicated that many U-turn accidents are, in fact, coded as left-turn accidents. Specifically, at some nonintersection median openings, where all movements through the median opening are, by definition, U-turns, many accidents are coded as left-turn accidents. The database included 79 U-turn accidents (1.1%) and 1,293 left-turn accidents (16.8%) for a total of 1,372 U-turn-plus-left-turn accidents (17.8%).

Tables 25 through 27 present accident frequencies by median opening type, number of legs, and intersection geometry, respectively. U-turn and left-turn accidents are presented

TABLE 25 Distribution of accidents by median opening type

Median opening type	No. of median openings	Number of accidents: U-turn	Left turn	U-turn and left turn	Total	Percentage of total accidents: U-turn	Left turn	U-turn and left turn
Midblock								
1a	37	4	13	17	185	2.2	7.0	9.2
1b	7	0	6	6	73	0.0	8.2	8.2
2b	145	6	125	131	1,423	0.4	8.8	9.2
2c	10	2	3	5	82	2.4	3.7	6.1
Three-leg								
3a	83	2	112	114	640	0.3	17.5	17.8
3b	121	26	253	279	1,367	1.9	18.5	20.4
3c	24	1	35	36	273	0.4	12.8	13.2
4a	21	2	49	51	418	0.5	11.7	12.2
Four-leg								
5a	84	4	116	120	750	0.5	15.5	16.0
5b	125	27	458	485	2,044	1.3	22.4	23.7
6a	11	5	123	128	353	1.4	34.8	36.3

TABLE 26 Distribution of accident by number of legs at intersection

Crossing type	No. of median openings	Number of accidents: U-turn	Left turn	U-turn and left turn	Total	Percentage of total accidents: U-turn	Left turn	U-turn and left turn
Midblock	199	12	147	159	1,763	0.7	8.3	9.0
Three-leg	249	31	449	480	2,698	1.1	16.6	17.7
Four-leg	220	36	697	733	3,147	1.1	22.1	23.2

TABLE 27 Distribution of accidents by type of geometry

Geometry type	No. of median openings	Number of accidents				Percentage of total accidents		
		U-turn	Left turn	U-turn and left turn	Total	U-turn	Left turn	U-turn and left turn
Conventional	481	64	993	1,057	5,332	1.2	18.6	19.8
Directional	187	15	300	315	2,276	0.7	13.2	13.9

separately as well as in combination. The tables shown here are simply meant to illustrate various distributions of the accident data and are not intended to present any conclusive relationships.

Analysis of Traffic Conflicts and Driver Behavior at Existing Median Openings

The videotapes recorded during the field data collection effort were reviewed to document how drivers behave in making U-turns and left turns through unsignalized median openings. Approximately, 152 hours of videotapes from 26 urban sites were reviewed. In general, seven types of undesirable driving behavior, or unsafe driving conditions, were observed. Each one is presented below, followed by a discussion of the causes of that behavior.

- **Vehicles slow in response to turning vehicle(s)**—The median geometry is such that there is no deceleration lane or storage area for a vehicle making a left turn or U-turn so that the deceleration of the turning vehicle must take place in the through travel lane (major road–same direction). The median may also be of insufficient width to store the vehicle once it has slowed or stopped, which can lead to other problems. This problem is exacerbated for trucks.
- **Vehicles queue in response to turning vehicle(s)**—The median geometry, or the lack of sufficient gaps of adequate length in the opposing traffic stream (major road), is such that when one (or multiple) vehicles attempt to turn, the queue spills back into the through travel lane (major road—same direction). This problem is exacerbated for trucks.
- **Vehicles drive in the wrong direction in the median**—For locations where there is a raised median separating the directional flows of traffic on the median roadway, drivers sometimes drive in the wrong direction on the median roadway. This may be because of poor median opening design, which confuses the driver or because of total disregard for the general rules of the road where the driver recognizes the proper operation of the opening but decides to perform an undesirable maneuver despite the cues presented at the opening.
- **Drivers making turns use the same gap**—For locations where there is a lack of adequate gaps of sufficient length, multiple vehicles making multiple maneuvers will use the same gap. This situation may be exacerbated as the number of lanes in the cross-section increases, because the task of finding a gap in three lanes of oncoming traffic (from one direction of travel on the major road) is not a simple task. Given the lack of any formal priority scheme for the performance of these different maneuvers, drivers will cut off other drivers, hesitate in initiating or completing their maneuver, or take a circuitous path in completing their maneuver.
- **Drivers make a "discontinuous" U-turn**—The cross-section configuration [primarily the combination of the median and the opposite (major) roadway] is such that there is not enough area to accommodate the turning radius of the vehicle. The compensating behavior by the driver is to shift the vehicle into reverse, turn the wheels to redirect the vehicle, shift the vehicle back to drive, and complete the U-turn (or what is often called a "K" or 3-Point-turn).
- **Drivers make a turn not served by the design of the intersection**—Some median openings are designed to accommodate only a limited number of turn maneuvers (e.g., left in, but not left out). Drivers proceeding from the minor roadway (or driveway) attempt (and usually complete) a left turn through a median opening not designed for such a maneuver. This may be result from a lack of knowledge of where the driver may be allowed to direct his vehicle to the opposite side of the major road. This behavior also could result from a sense of frustration because the driver could enter the minor roadway (or driveway) from the major roadway by performing a left turn, but cannot "re-enter" that same roadway by again performing a left turn.
- **Drivers hesitate when entering the median roadway**—Drivers will hesitate when entering the median roadway when they are unsure of what maneuver a driver already in the median roadway is attempting. For example, if a driver entering the median roadway from the major road is attempting to make a U-turn and a second driver entering the median roadway from the major road (opposite direction) is attempting a left turn maneuver, the second driver may not understand the intention of the first driver and does not know whether to turn "in front of" or "behind" the first vehicle. The driver of the second vehicle hesitates and waits in the through lane of the major

road (opposite direction) until able to ascertain the driver of the first vehicle's intended maneuver.

For purposes of conducting a traffic conflict analysis, the seven types of undesirable driver behavior were grouped into three conflict types:

- *Conflict Type A*: A vehicle turning from the major road into the median opening causes the following vehicle on the major road to brake. This conflict type includes the following undesirable driving behaviors: (1) vehicles slow in response to turning vehicle, (2) vehicles queue up in response to turning vehicle, and (3) drivers hesitate when entering the median roadway.
- *Conflict Type B*: Conflict between two or more vehicles within the median opening. This conflict type includes the following undesirable driving behaviors: (1) vehicles drive in the wrong direction in the median and (2) drivers make a turn not served by the design of the intersection.
- *Conflict Type C*: A vehicle turning from the median opening onto the major road causes the vehicle on the major road to brake. This conflict type includes the following undesirable driving behaviors: (1) drivers making turns use the same gap and (2) drivers make a "discontinuous" U-turn.

Table 28 summarizes the traffic conflict data collected during the videotape studies.

TABLE 28 Summary of data for traffic conflict analysis

Type	Total hours of videotape	Turning counts: Major-road U-turn	Major-road left turn	Minor-road left turn	Total major-road volume	Number of conflicts	Number of conflicts (per 10^3 turning vehicles)	Number of conflicts by conflict type: A[a]	B[b]	C[c]
URBAN ARTERIAL CORRIDORS										
Midblock										
2b	24	2,103	0	0	50,367	6	2.9	1	0	5
2c	29	1,746	0	0	72,351	36	20.6	0	1	35
Three-leg										
3b	36	758	888	221	63,472	12	6.4	4	2	6
4a	21	546	524	192	52,469	43	34.1	6	0	37
Four-leg										
5a	12	424	568	493	27,713	19	12.8	17	2	0
5b	24	689	1,792	565	68,721	31	10.2	7	5	19
6a	6	421	303	0	19,814	20	27.6	1	0	19

[a] Conflict Type A: Vehicle turning from the major road into the median opening causes following vehicle on the major road to brake.
[b] Conflict Type B: Conflict between two or more vehicles within the median opening.
[c] Conflict Type C: Vehicle turning from the median opening onto the major road causes vehicle on the major road to brake.

CHAPTER 6

FINDINGS

This chapter presents the findings of the research. The issues addressed in this chapter are accident and field data, median opening accident frequencies, median opening accident rates, median opening traffic conflicts, comparison of accident rates and conflict rates, and combinations of median opening types.

ACCIDENT AND FIELD DATA

Table 29 presents the number of unsignalized median opening sites in each of the following categories:

- Median openings in the original catalog,
- Median openings with accident data available,
- Median openings where field data (either videotape studies or supplementary traffic counts) were collected, and
- Median openings with both accident and field data.

The median openings in the original catalog are all of the unsignalized median openings that were visited and documented in the field. They represent all of the original median openings available for possible inclusion in the analyses. However, accident data were not available for all of the median openings. In one state, accident data were available only for intersection locations (i.e., locations with a cross street). Thus, no accident data were available for midblock locations (Types 1a, 1b, 2b, and 2c). In other states, some of the corridors originally recommended by the participating highway agency—and which were included in the catalog of median opening types—were not maintained by the highway agency and, therefore, accident data were not available for these locations either. In Table 29, the columns under "Median openings with field data" illustrate the number of median openings where videotape studies were conducted ("Primary") and where 15-min counts were made ("Supplementary"). The last column represents the median openings with both accident and field data and, given that accident *and* traffic volume data are needed to conduct meaningful accident analyses, the median openings that were included in the analyses. Thus, the project database includes 115 unsignalized median opening sites with both accident and field data.

Table 30 summarizes traffic volume data by median opening type. The average major-road ADT is fairly consistent across all median opening types, with the exceptions of Type 1a (i.e., conventional midblock median opening without left-turn lanes) and Type 3a (i.e., conventional median opening without left-turn lanes at three-leg intersection), which each have about one-half the average ADT on the major road.

The median opening volumes represent all U-turns and left turns that go through the median opening, including left turns from the minor road; these volumes are based on counts made during the field studies. The midblock median openings (Types 1a, 2b, and 2c) have no left-turn volumes given that, by design, they accommodate only U-turn traffic. The median opening volumes constitute a small percentage of the major road volumes, ranging from 0.0 to 4.2 percent.

MEDIAN OPENING ACCIDENT FREQUENCIES

Tables 31 through 33 present frequencies of total accidents, fatal and injury accidents, and PDO accidents, respectively, by median opening type. U-turn and left-turn accident frequencies are presented separately as well as in combination. These frequencies should not be considered conclusions about the relative safety of various designs because they do not consider traffic volumes (i.e., median types showing more accidents may also have had higher traffic volumes).

Table 31 demonstrates that accidents related to U-turn and left-turn maneuvers at unsignalized median openings occur very infrequently. The 103 median openings in urban arterial corridors experienced an average of 0.41 U-turn plus left-turn accidents per median opening per year. The 12 median openings in rural arterial corridors experienced an average of 0.20 accidents per median opening per year. Overall, at these median openings, U-turns represent 58 percent of the median opening movements and left turns represent 42 percent of the median opening movements. Based on these limited accident frequencies, there is no indication that U-turns at unsignalized median openings constitute a major safety concern.

Table 34 presents the distribution of collision types by median opening type. Collision types are as follows:

- *Major-road angle collision*—collision between a major-road through vehicle and a vehicle turning from the median opening onto the major road (i.e., either a left-turning vehicle or a U-turn vehicle)

TABLE 29 Number of unsignalized median opening sites

Median opening type	Median openings in original catalog	Median openings with accident data available	Median openings with field data			Median openings with both accident and field data
			Primary	Supplementary	Total	
URBAN ARTERIAL CORRIDORS						
Midblock						
1a	12	10	0	7	7	7
1b	23	1	0	1	1	0
2b	149	145	8	12	20	20
2c	11	10	5	8	13	10
Three-leg						
3a	44	34	1	10	11	11
3b	183	99	5	25	30	19
3c	4	4	0	2	2	2
4a	37	20	4	7	11	4
4b	1	0	0	0	0	0
Four-leg						
5a	43	41	2	6	8	8
5b	164	106	4	26	30	17
6a	14	10	1	5	6	5
Subtotal	685	480	30	109	139	103
RURAL ARTERIAL CORRIDORS						
Midblock						
1a	29	27	1	6	7	7
1b	6	6	0	0	0	0
2a	1	0	0	0	0	0
2c	1	0	0	0	0	0
Three-leg						
3a	63	49	0	4	4	4
3b	24	22	0	0	0	0
3c	21	21	0	0	0	0
4a	2	1	0	0	0	0
Four-leg						
5a	55	43	1	0	1	1
5b	20	19	0	0	0	0
5c	2	2	0	0	0	0
6a	1	1	0	0	0	0
Subtotal	225	191	2	10	12	12
TOTAL	910	671	32	119	151	115

- *Major-road rear-end collision*—collision between a vehicle making either a U-turn or left-turn from the major road into the median opening and a following major-road through vehicle
- *Cross-street collision*—any collision involving a vehicle from the cross street
- *Other or unknown collision type*—collision where the intended vehicle movements are unknown

MEDIAN OPENING ACCIDENT RATES

Table 35 presents total median opening accident rate by median opening type. The median opening accident rate consists of the number of accidents involving either a U-turn or left turn through the median opening per million vehicles turning through the median opening.

For urban arterial corridors, median opening accident rates are substantially lower for midblock median openings than for median openings at three-leg and four-leg intersections. For example, the accident rate per million median opening movements (i.e., U-turn plus left-turn maneuvers) at a directional midblock median opening is typically only about 14 percent of the median opening accident rate for a directional median opening at a three-leg intersection. At conventional three-leg median openings, the average median opening accident rate at median openings with two left-turn lanes (Type 3c) is substantially higher than the average median

TABLE 30 Turning volumes at median openings

Median opening type	Number of median openings	Average two-way major-road ADT[a] (veh/day)	Turning volume at median openings (veh/day) U-turn	Left turn	Total	(percentage of major road ADT) U-turn	Left turn	Total	(percentage of total median opening ADT) U-turn	Left turn
URBAN ARTERIAL CORRIDORS										
Midblock										
1a	7	13,161	2	0	2	0.01	0.00	0.01	100.00	0.00
2b	20	33,495	700	0	700	2.09	0.00	2.09	100.00	0.00
2c	10	30,231	977	0	977	3.23	0.00	3.23	100.00	0.00
Three-leg										
3a	11	14,446	11	95	106	0.08	0.66	0.74	10.38	89.62
3b	19	32,760	248	187	435	0.76	0.57	1.33	57.01	42.99
3c	2	42,361	79	307	386	0.19	0.72	0.91	20.47	79.53
4a	4	31,366	138	680	818	0.44	2.17	2.61	16.87	83.13
Four-leg										
5a	8	34,324	259	622	881	0.75	1.81	2.56	29.40	70.60
5b	17	40,096	285	533	818	0.71	1.33	2.04	34.84	65.16
6a	5	38,476	552	1,065	1,617	1.43	2.77	4.20	34.14	65.86
RURAL ARTERIAL CORRIDORS										
Midblock										
1a	7	21,309	88	0	88	0.41	0.00	0.41	100.00	0.00
Three-leg										
3a	4	27,448	374	404	778	1.36	1.47	2.83	48.07	51.93
Four-leg										
5a	1	28,126	346	555	901	1.23	1.97	3.20	38.40	61.60

[a] Major-road and median-opening volumes for year 2002.

TABLE 31 Median opening accident frequency by median opening type

Median opening type	Number of median openings	Median opening accident frequency[a] (for entire study period) U-turn	Left-turn	Total	Median opening accident frequency (per median opening per year) U-turn	Left-turn	Total
URBAN ARTERIAL CORRIDORS							
Midblock							
1a	7	1	0	1	0.029	0.000	0.029
2b	20	1	3	4	0.010	0.030	0.040
2c	10	2	3	5	0.040	0.060	0.100
Three-leg							
3a	11	1	8	9	0.018	0.145	0.164
3b	19	5	27	32	0.055	0.297	0.352
3c	2	0	10	10	0.000	1.000	1.000
4a	4	0	7	7	0.000	0.304	0.304
Four-leg							
5a	8	0	26	26	0.000	0.650	0.650
5b	17	5	71	76	0.056	0.798	0.854
6a	5	3	39	42	0.100	1.300	1.400
RURAL ARTERIAL CORRIDORS							
Midblock							
1a	7	0	3	3	0.000	0.088	0.088
Three-leg							
3a	4	0	4	4	0.000	0.235	0.235
Four-leg							
5a	1	2	2	4	0.500	0.500	1.000

[a] The study period was generally five years in duration. However, only four years of accident data were available for sites in New Jersey, and six years of accident data were available for sites in New York.

TABLE 32 Fatal-and-injury median opening accident frequency by median opening type

Median opening type	Number of median openings	Median opening accident frequency[a] (for entire study period) U-turn	Left-turn	Total	Median opening accident frequency (per median opening per year) U-turn	Left-turn	Total
URBAN ARTERIAL CORRIDORS							
Midblock							
1a	7	1	0	1	0.029	0.000	0.029
2b	20	1	2	3	0.010	0.020	0.030
2c	10	1	0	1	0.020	0.000	0.020
Three-leg							
3a	11	1	3	4	0.018	0.055	0.073
3b	19	0	13	13	0.000	0.143	0.143
3c	2	0	6	6	0.000	0.600	0.600
4a	4	0	4	4	0.000	0.174	0.174
Four-leg							
5a	8	0	10	10	0.000	0.250	0.250
5b	17	0	24	24	0.000	0.270	0.270
6a	5	2	25	27	0.067	0.833	0.900
RURAL ARTERIAL CORRIDORS							
Midblock							
1a	7	0	2	2	0.000	0.059	0.059
Three-leg							
3a	4	0	1	1	0.000	0.059	0.059
Four-leg							
5a	1	0	0	0	0.000	0.000	0.000

[a] The study period was generally five years in duration. However, only four years of accident data were available for sites in New Jersey, and six years of accident data were available for sites in New York.

opening accident rate at median openings with either no left-turn lane or only one left-turn lane, but the data reflect only two median openings of Type 3c. Furthermore, the data showed considerable state-to-state variation that could not be accounted for with a database of this size. Comparing median openings at three-leg intersections, average median opening accident rates for directional three-leg median openings are about 48 percent lower than the accident rates for conventional three-leg median openings. Comparing median openings at four-leg intersections, average median opening accident rates for directional four-leg median openings are about 15 percent lower than for conventional four-leg intersections.

For rural arterial corridors, the average median opening accident rate is lower for median openings at three-leg intersections than for median openings at four-leg intersections. However, the sample size of median openings and median-opening-related accidents for rural arterial corridors is so small that no firm conclusions can be drawn.

Comparable results for fatal-and-injury and property-damage-only accident rates at median openings are presented in Tables 36 and 37.

MEDIAN OPENING CONFLICT RATES

An analysis of traffic conflicts was conducted and is described in Chapter 5. The videotape recordings made during the field data collection effort were reviewed to document how drivers behave in making U-turns and left turns through unsignalized median openings. Three basic conflict types were observed and analyzed:

- *Conflict Type A*: A vehicle turning from the major road into the median opening causes the following vehicle on the major road to brake.
- *Conflict Type B*: Conflict between two or more vehicles within the median opening.
- *Conflict Type C*: A vehicle turning from the median opening onto the major road causes the vehicle on the major road to brake.

Table 38 summarizes traffic conflicts by median opening type. Some observations from the table are as follows:

TABLE 33 Property-damage-only median opening accident frequency by median opening type

Median opening type	Number of median openings	Median opening accident frequency[a] (for entire study period)			Median opening accident frequency (per median opening per year)		
		U-turn	Left-turn	Total	U-turn	Left-turn	Total
URBAN ARTERIAL CORRIDORS							
Midblock							
1a	7	0	0	0	0.000	0.000	0.000
2b	20	0	1	1	0.000	0.010	0.010
2c	10	1	3	4	0.020	0.060	0.080
Three-leg							
3a	11	0	5	5	0.000	0.091	0.091
3b	19	5	14	19	0.055	0.154	0.209
3c	2	0	4	4	0.000	0.400	0.400
4a	4	0	3	3	0.000	0.130	0.130
Four-leg							
5a	8	0	16	16	0.000	0.400	0.400
5b	17	5	47	52	0.056	0.528	0.584
6a	5	1	14	15	0.033	0.467	0.500
RURAL ARTERIAL CORRIDORS							
Midblock							
1a	7	0	1	1	0.000	0.029	0.029
Three-leg							
3a	4	0	3	3	0.000	0.176	0.176
Four-leg							
5a	1	2	2	4	0.500	0.500	1.000

[a] The study period was generally five years in duration. However, only four years of accident data were available for sites in New Jersey, and six years of accident data were available for sites in New York.

- Most traffic conflicts at midblock median openings and median openings at three-leg intersections, particularly directional median openings, were related to the turning vehicle merging onto the major road from the median opening (Conflict Type C).
- At median openings without left-turn lanes at four-leg intersections, most of the traffic conflicts were related to vehicles turning from the major road into the median opening (Conflict Type A).
- At directional median openings (Types 2b, 2c, 4a, and 6a), the greatest problem appears to be related to vehicles merging onto the major road from the median opening, as evidenced by the large number of Type C traffic conflicts.

COMPARISON OF MEDIAN OPENING ACCIDENT AND CONFLICT RATES

Table 39 presents median opening accident and conflict rates by geometry type and number of intersection legs. All of the median openings are urban. Relative safety comparisons that can be made from the table include the following:

- Median opening accident rates are substantially lower for midblock median openings than for median openings at three- and four-leg intersections. For example, the median opening accident rate at a directional midblock median opening is typically only about 14 percent of the median opening accident rate for a directional median opening at a three-leg intersection.
- Median opening accident rates are slightly lower at conventional three-leg median openings than at conventional four-leg median openings. Median opening conflict rates at conventional three-leg median openings are almost half the conflict rates at conventional four-leg median openings.
- Median opening accident rates at directional three-leg median openings are about 48 percent lower than the accident rates for conventional three-leg openings. In contrast, median opening conflict rates at directional three-leg median openings are substantially higher than the conflict rates for conventional three-leg openings.
- Median opening accident rates at directional four-leg median openings are about 15 percent lower than for conventional four-leg intersections. In contrast, median opening conflict rates at directional four-leg median

TABLE 34 Collision type distribution for median opening turning accidents

Median opening type	Number of median openings	Accident frequency by collision type[a] (for entire study period): Major-road angle	Major-road rear end	Cross street	Other or unknown	Total	Percentage of accident frequency by collision type: Major road angle	Major-road rear end	Cross street	Other or unknown
URBAN ARTERIAL CORRIDORS										
Midblock										
1a	7	1	0	0	0	1	100.0	0.0	0.0	0.0
2b	20	2	2	0	0	4	50.0	50.0	0.0	0.0
2c	10	1	3	0	1	5	20.0	60.0	0.0	20.0
Three-leg										
3a	11	0	4	4	1	9	0.0	44.4	44.4	11.1
3b	19	8	5	18	1	32	25.0	15.6	56.3	3.1
3c	2	9	1	0	0	10	90.0	10.0	0.0	0.0
4a	4	7	0	0	0	7	100.0	0.0	0.0	0.0
Four-leg										
5a	8	16	8	2	0	26	61.5	30.8	7.7	0.0
5b	17	28	33	12	3	76	36.8	43.4	15.8	3.9
6a	5	35	2	3	2	42	83.3	4.8	7.1	4.8
RURAL ARTERIAL CORRIDORS										
Midblock										
1a	7	0	2	1	0	3	0.0	66.7	33.3	0.0
Three-leg										
3a	4	0	3	1	0	4	0.0	75.0	25.0	0.0
Four-leg										
5a	1	1	2	1	0	4	25.0	50.0	25.0	0.0

[a] The duration of the study period was generally five years. However, only four years of accident and exposure data were available for sites in New Jersey, and six years of accident and exposure data were available for sites in New York.

TABLE 35 Total median opening accident rate by median opening type

Median opening type	Number of median openings	Total median opening accident frequency[a] (for entire study period)	Median opening movements (10^6 turns during entire study period)	Median opening accident rate (accidents per 10^6 turning vehicles)
URBAN ARTERIAL CORRIDORS				
Midblock				
1a	7	1	–[b]	–[b]
2b	20	4	17.20	0.23
2c	10	5	13.42	0.37
Three-leg				
3a	11	9	2.23	4.04
3b	19	32	13.04	2.46
3c	2	10	1.20	8.35
4a	4	7	4.87	1.44
Four-leg				
5a	8	26	11.16	2.33
5b	17	76	22.77	3.34
6a	5	42	16.36	2.57
RURAL ARTERIAL CORRIDORS				
Midblock				
1a	7	3	0.96	3.13
Three-leg				
3a	4	4	4.65	0.86
Four-leg				
5a	1	4	1.41	2.84

[a] The duration of the study period was generally five years. However, only four years of accident and exposure data were available for sites in New Jersey, and six years of accident and exposure data were available for sites in New York.
[b] Data too limited to be meaningful.

TABLE 36 Fatal-and-injury median opening accident rate by median opening type

Median opening type	Number of median openings	Total median opening accident frequency[a] (for entire study period)	Median opening movements (10^6 turns during entire study period)	Median opening accident rate (accidents per 10^6 turning vehicles)
URBAN ARTERIAL CORRIDORS				
Midblock				
1a	7	1	–[b]	–[b]
2b	20	3	17.20	0.17
2c	10	1	13.42	0.08
Three-leg				
3a	11	4	2.23	1.80
3b	19	13	13.04	1.00
3c	2	6	1.20	5.01
4a	4	4	4.87	0.82
Four-leg				
5a	8	10	11.16	0.90
5b	17	24	22.77	1.05
6a	5	27	16.36	1.65
RURAL ARTERIAL CORRIDORS				
Midblock				
1a	7	2	0.96	2.09
Three-leg				
3a	4	1	4.65	0.22
Four-leg				
5a	1	0	1.41	0.00

[a] The duration of the study period was generally five years. However, only four years of accident and exposure data were available for sites in New Jersey, and six years of accident and exposure data were available for sites in New York.
[b] Data too limited to be meaningful.

openings are more than twice the conflict rates at conventional four-leg median openings.

COMBINATIONS OF MEDIAN OPENINGS

Comparisons between the safety of conventional and directional median openings and between midblock median openings and median openings at three- and four-leg intersections are more reasonable when the number of movements allowed through each median opening type is included in the comparison. For example, median opening accident rates are substantially lower for midblock median openings than for median openings at three- and four-leg intersections. This is not surprising given that midblock median openings do not have cross-street traffic turning through the median opening, thus creating additional points of conflict. Similarly, median opening accident rates at directional three-leg median openings are about 48 percent lower than the accident rates for conventional three-leg openings. Directional three-leg median openings (Type 4a) only accommodate left turns and U-turns from the major road and do not permit left turns from the cross street. Therefore, to conduct a fair comparison of conventional and directional median openings at three-leg intersections, combinations of median openings should be compared. For example, a directional three-leg median opening in combination with a directional midblock median opening, as presented in Figure 47, is better compared with a conventional three-leg opening (Type 3b) because the same turning movements are accommodated in each situation.

This section presents several typical combinations of median opening designs that can be used along an arterial to accommodate the same turning movements allowed at an individual median opening. In each case, a safety comparison is made between the individual median opening and the combination of median openings.

Comparison of Conventional and Directional Median Openings at Three-Leg Intersections

A conventional median opening at a three-leg intersection (Type 3a, 3b, 3c, or 3d) accommodates all turning movements from the major road and cross street. A directional median

TABLE 37 Property-damage-only median opening accident rate by median opening type

Median opening type	Number of median openings	Total median opening accident frequency[a] (for entire study period)	Median opening movements (10^6 turns during entire study period)	Median opening accident rate (accidents per 10^6 turning vehicles)
URBAN ARTERIAL CORRIDORS				
Midblock				
1a	7	0	–[b]	–[b]
2b	20	1	17.20	0.06
2c	10	4	13.42	0.30
Three-leg				
3a	11	5	2.23	2.24
3b	19	19	13.04	1.46
3c	2	4	1.20	3.34
4a	4	3	4.87	0.62
Four-leg				
5a	8	16	11.16	1.43
5b	17	52	22.77	2.28
6a	5	15	16.36	0.92
RURAL ARTERIAL CORRIDORS				
Midblock				
1a	7	1	0.96	1.04
Three-leg				
3a	4	3	4.65	0.65
Four-leg				
5a	1	4	1.41	2.84

[a] The duration of the study period was generally five years. However, only four years of accident and exposure data were available for sites in New Jersey, and six years of accident and exposure data were available for sites in New York.
[b] Data too limited to be meaningful.

TABLE 38 Summary of traffic conflicts by median opening type at urban sites

Type	Number of conflicts	No. of conflicts per 10^3 major-road vehicles	Number of conflicts by conflict type		
			A[a]	B[b]	C[c]
Midblock					
2b	6	2.9	1	0	5
2c	36	20.6	0	1	35
Three-leg					
3b	12	6.4	4	2	6
4a	43	34.1	6	0	37
Four-leg					
5a	19	12.8	17	2	0
5b	31	10.2	7	5	19
6a	20	27.6	1	0	19

[a] Conflict Type A: Vehicle turning from the major road into the median opening causes following vehicle on the major road to brake.
[b] Conflict Type B: Conflict between two or more vehicles within the median opening.
[c] Conflict Type C: Vehicle turning from the median opening onto the major road causes vehicle on the major road to brake.

TABLE 39 Median opening accident and conflict rates by geometry type and number of intersection legs at urban sites

Median opening type	Number of median openings	Number of accidents	Median opening movements (10^6 turns during entire study period)	Median opening accident rate (accidents per 10^6 turning vehicles)	Conflict rate (conflicts per 10^3 major-road vehicles)
Directional midblock (2b + 2c)	30	9	30.62	0.29	11.0
Conventional 3-leg (3a + 3b)	30	41	15.27	2.69	6.4[a]
Directional 3-leg (4a)	4	7	4.87	1.40	34.1
Conventional 4-leg (5a + 5b)	25	102	33.93	3.01	11.0
Directional 4-leg (6a)	5	42	16.36	2.57	27.6

[a] Conflict data collected at Type 3b median openings only.

opening at a three-leg intersection accommodates only left turns from the major road to the cross street (Type 4a) or left turns from the cross street to the major road (Type 4b). Therefore, a directional median opening at a three-leg intersection may be used in combination with a directional midblock median opening (Type 2a or 2b) to indirectly accommodate all turning movements. Figure 47 presents a conventional median opening at a three-leg intersection (Type 3b) and a combination of a directional median opening at a three-leg intersection (Type 4a) with a directional midblock median opening (Type 2b).

From Table 39, the median opening accident rate for a conventional median opening at a three-leg intersection (Type 3a + 3b) is 2.69 accidents per million turning vehicles. From Tables 35 and 39, the median opening accident rate for the combination of directional median openings is 1.63 accidents per million turning vehicles (1.40 for the Type 4a median opening plus 0.233 for the Type 2b median opening). Thus, the median opening accident rate for the combination of directional median openings is about 40 percent less than the accident rate for a conventional median opening at a three-leg intersection.

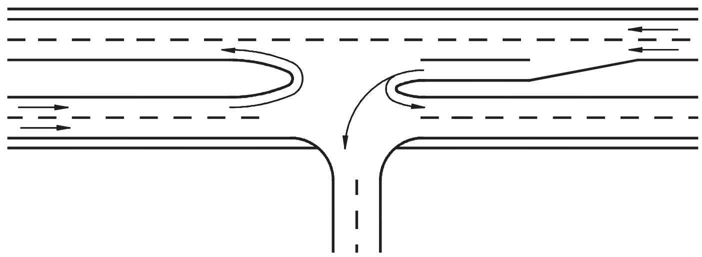
Comparison of Conventional and Directional Median Openings at Four-Leg Intersections

A conventional median opening at a four-leg intersection (Type 5a, 5b, or 5c) accommodates all turning movements from the major road and cross street as well as through movements on the cross street. A directional median opening at a four-leg intersection accommodates only left turns from the major road to the cross street (Type 6a). Therefore, a directional median opening at a four-leg intersection may be used in combination with two directional midblock median openings (Type 2a or 2b) to indirectly accommodate all turning movements. Figure 48 presents a conventional median opening at a four-leg intersection (Type 5b) and a combination of a directional median opening at a four-leg intersection (Type 6a) with two directional midblock median openings (Type 2b).

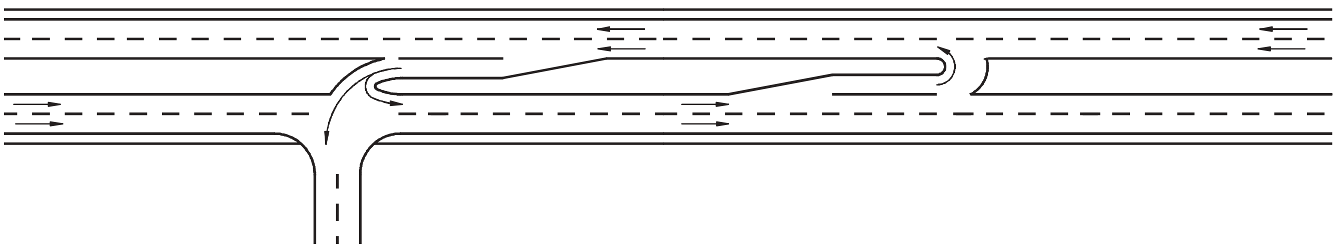
From Table 39, the median opening accident rate for a conventional median opening at a four-leg intersection (Type 5a + 5b) is 3.01 accidents per million turning vehicles. From Tables 34 and 39, the median opening accident rate for the combination of directional median openings is 3.03 accidents per million turning vehicles (2.57 for the Type 6a median opening plus 0.46 for two Type 2b median openings), which is about equal to the median opening accident rate for the conventional median opening.

Comparison of Conventional and Directional Median Openings at Signalized Four-Leg Intersections

Although the focus of the research was on unsignalized median openings, most of the directional midblock median openings in the study were sites in Michigan, where they are used in combination with signalized intersections. At these locations, left turns are prohibited from the major and minor road at the signalized intersection. From the minor road, left-turning traffic turns right onto the divided road and then makes a U-turn at the directonal midblock median opening. Traffic turning left from the major road must first travel



a) Conventional Median Opening at Three-Leg Intersection (Type 3b)

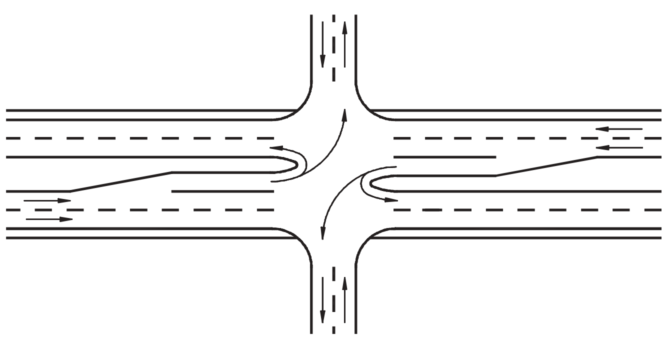


b) Directional Median Opening For Left Turns From Major Road at Three-Leg Intersection With Directional Midblock Median Opening (Type 4a + Type 2b)

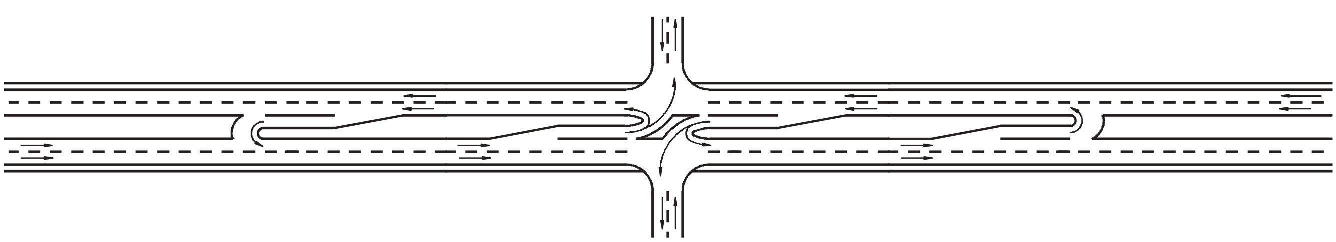
Figure 47. Conventional and directional median openings at three-leg intersection.

through the intersection and then make a U-turn at the directional midblock median opening, followed by a right turn onto the minor road.

Figure 49 illustrates a conventional signalized four-leg intersection and a combination of directional midblock median openings with a signalized intersection where turns are prohibited. Without a formal safety prediction model for signalized intersections on divided highways that is sensitive to turning volumes, no formal comparison of the relative safety of the two scenarios (conventional and directional median openings at signalized four-leg intersections) can be made. However, given that the median opening accident rate for directional midblock median openings is so low, it is likely that the safety performance of the directional median opening combination, as used in Michigan, is as good as or better than the safety performance of the conventional median opening.

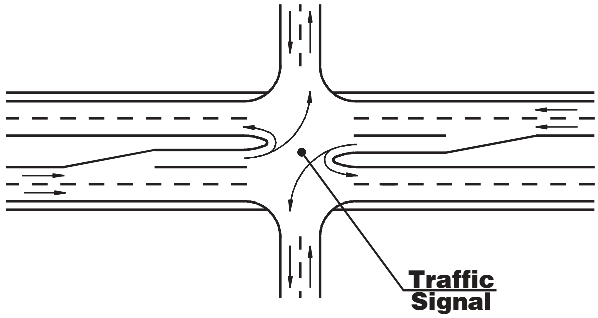


a) Conventional Median Opening at Four-Leg Intersection (Type 5b)

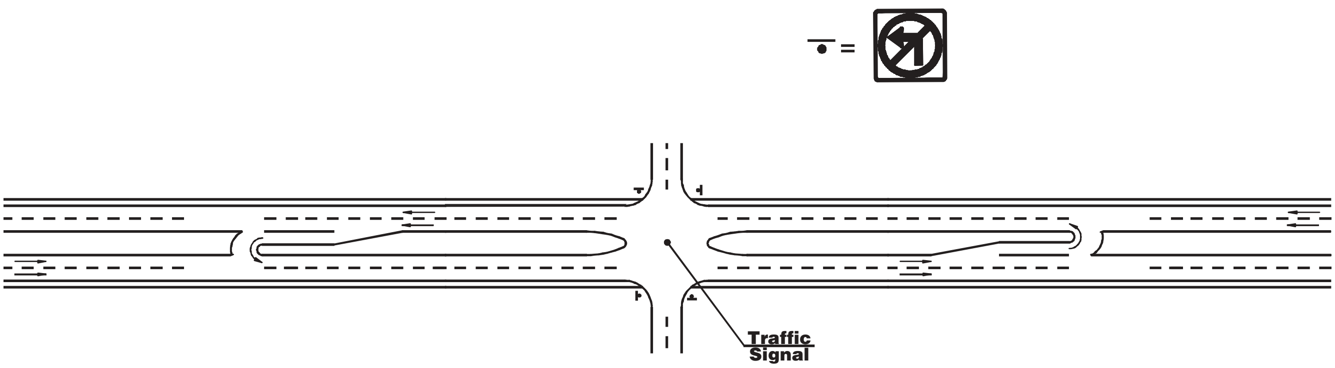


b) Directional Median Opening Four-Leg Intersection With Two Directional Midblock Median Openings (Type 2b + Type 6a + Type 2b)

Figure 48. Conventional and directional median openings at four-leg intersection.



a) Conventional Median Opening at Signalized Four-Leg Intersection



b) Signalized Four-Leg Intersection With No Turns Permitted and Two Directional Midblock Median Openings

Figure 49. Median openings at signalized four-leg intersection.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions of the research and recommendations for future work.

CONCLUSIONS

The conclusions of the research are as follows:

- As medians are used more extensively on arterial highways, with direct left-turn access limited to selected locations, many arterial highways experience fewer midblock left-turn maneuvers and more U-turn maneuvers at unsignalized median openings.
- Field studies at various median opening types in urban arterial corridors have found estimated U-turn volumes ranging from 2 to 977 veh/day, representing from 0.01 to 3.2 percent of the major-road traffic volumes at those locations. At median openings in rural areas, U-turn volumes were found to range up to 374 veh/day, representing at most 1.4 percent of the major-road traffic volumes at those locations.
- Review of accident data for median openings at which U-turn maneuvers are made have found that accident report data do not distinguish clearly between accidents involving U-turn maneuvers and those involving left-turn maneuvers. In particular, at some median openings where U-turn maneuvers can be made but no left-turn maneuvers are feasible, investigating officers classified a substantial proportion of the accidents involving turning movements through the median as related to left-turn maneuvers. For this reason, reliable evaluation of median opening accident frequency must necessarily consider the frequency of U-turn-related and left-turn-related accidents combined.
- Accidents related to U-turn and left-turn maneuvers at unsignalized median openings occur very infrequently. The 103 median openings in urban arterial corridors evaluated in detail in this research experienced an average of 0.41 U-turn plus left-turn accidents per median opening per year. The 12 median openings in rural arterial corridors evaluated in detail in this research experienced an average of 0.20 accidents per median opening per year. Overall, at these median openings, U-turns represent 58 percent of the median opening movements and left turns represent 42 percent of the median opening movements. Based on these limited accident frequencies, there is no indication that U-turns at unsignalized median openings constitute a major safety concern.
- Average accident rates per median opening movement (U-turn plus left-turn maneuvers) have been estimated for specific median opening types in both urban and rural arterial corridors. No satisfactory regression relationships relating median opening accident frequency to the volume of U-turn and left-turn maneuvers through the median opening could be developed. Given the low accident frequencies, this is not surprising.
- For urban arterial corridors, median opening accident rates are substantially lower for midblock median openings than for median openings at three- and four-leg intersections. For example, the accident rate per million median opening movements (U-turn plus left-turn maneuvers) at a directional midblock median opening is typically only about 14 percent of the median opening accident rate for a directional median opening at a three-leg intersection.
- For urban arterial corridors, average median opening accident rates are slightly lower for conventional three-leg median openings than for conventional four-leg median openings
- For urban arterial corridors, average median opening accident rates for directional three-leg median openings are about 48 percent lower than the accident rates for conventional three-leg median openings.
- For urban arterial corridors, average median opening accident rates for directional four-leg median openings are about 15 percent lower than for conventional four-leg intersections.
- For rural arterial corridors, the average median opening accident rate is lower for median openings at three-leg intersections than for median openings at four-leg intersections. However, the sample size of median openings and median-opening-related accidents for rural arterial corridors is so small that no firm conclusions can be drawn.
- Where directional median openings are considered as alternatives to conventional median openings, two or more directional median openings are usually required

to serve the same traffic movements as one conventional median opening. Therefore, design decisions should consider the relative safety and operational efficiency of all directional median openings in comparison with the single conventional median opening.

- A comparison of the total median opening accident rates for the range of median opening types considered in the research is presented in Table 35. Comparable results for fatal-and-injury and property-damage-only accident rates at median openings are presented in Tables 36 and 37.
- Analysis of field data found that, for most types of median openings, most observed traffic conflicts involved major-road through vehicles having to brake for vehicles turning from the median opening onto the major road.
- For median openings at four-leg intersections without left-turn lanes on the major road, most of the observed traffic conflicts involved major-road through vehicles having to brake for vehicles turning left into the median opening.
- The minimum spacing between median openings currently used by highway agencies in rural areas ranges from 152 to 805 m (500 to 2,640 ft). In urban areas, the minimum spacing between median openings ranges from 91 to 805 m (300 to 2,640 ft) in highway agency policies. In most cases, highway agencies use spacings between median openings in the upper end of these ranges, but there is no indication that safety problems result from occasional use of median opening spacings as short as 91 to 152 m (300 to 500 ft).

RECOMMENDATIONS

The following recommendations have been developed based on these conclusions:

- Guidelines for the use, location, and design of unsignalized median openings are included in Appendix C of this report.
- The guidelines include tables presenting the advantages and disadvantages of typical median opening designs; these tables should be used by designers as a resource when considering alternative median opening designs.
- A methodology for comparing the expected safety performance of median opening design alternatives, as presented in Appendix C, should be used to assist in the selection of median opening types and the comparison of alternative median opening arrangements.
- Unsignalized median openings may be used for a broad range of major- and minor-road traffic volumes. However, if the major- and minor-road volumes exceed the traffic volumes given in the MUTCD signalization warrants, signalization of the median opening should be considered.
- When evaluating the safety performance of unsignalized median openings, highway agencies should take into account both U-turn and left-turn maneuvers because accident report data do not distinguish clearly between accidents involving U-turn maneuvers and those involving left-turn maneuvers.
- Median widths at suburban unsignalized intersections generally should be as narrow as possible while providing sufficient space in the median for the appropriate left-turn treatment and to accommodate U-turn maneuvers by a selected design vehicle.
- Rural unsignalized intersections should have medians that are as wide as practical, as long as the median is not so wide that approaching vehicles on the crossroad cannot see both roadways of the divided highway.
- Median opening lengths at urban and suburban divided highway intersections may be as long as necessary. In contrast, median opening lengths at rural divided highway intersections generally should be kept to the minimum possible.
- Intersection sight distance based on the criteria in the AASHTO Green Book (*3*) for Cases B1, B2, and F should be available to accommodate U-turns and left turns at unsignalized median openings.
- Where a large truck is used as the design vehicle for a median opening and a median width of 21 to 31 m (70 to 100 ft) cannot be provided, consideration should be given to providing a loon.
- Left-turn lanes on the major road are desirable to minimize conflicts between through and turning vehicles at unsignalized median openings.
- Midblock median openings should be considered, where appropriate, as a supplement or an alternative to median openings at three-leg or four-leg intersections.
- Directional median openings at three-leg intersections, combined with a directional midblock median opening, should be considered as a supplement or an alternative to conventional median openings at three-leg intersections.
- Directional median openings at four-leg intersections, combined with two directional midblock median openings, should be considered as a supplement or an alternative to conventional median openings at four-leg intersections.

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APPENDIX A

HIGHWAY AGENCY SURVEY QUESTIONNAIRE

National Cooperative Highway Research Program
Project 17-21

"Safety of U-Turns at Unsignalized Median Openings"

The following survey on the safety of U-turns at unsignalized median openings 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 the following questions concerning your agency's geometric design policies regarding the design of U-turns at unsignalized median openings would be greatly appreciated.

STATE MEDIAN OPENING SURVEY QUESTIONNAIRE

*(Please return by **July 31, 2001**)*

STATE/AGENCY: ________________

GENERAL

1. What criteria are used by your agency to determine where to allow an opening in a nontraversable median?

____

____

____

2. What types of median openings are designed and operated by your agency? In particular, does your agency use directional median openings or median openings at which some turning movements are prohibited by design features such as channelization?

____

____

POLICIES

3. Does your agency have a policy concerning minimum spacing between median openings? .... ☐Yes ☐No

   If YES, does this policy differ in rural and urban/suburban areas? .... ☐Yes ☐No

   If YES to either question, please attach a copy of your policy.

4. Does your agency have a formal policy concerning the location of **unsignalized** median openings (sight distance, spacing from other intersections or signals, etc.)? .... ☐Yes ☐No

   If YES, please summarize below or attach a copy of your policy.

   ____

   ____

   ____

5. Does your agency require the installation of left-turn lanes at unsignalized median openings? .... ☐Yes ☐No

   If YES, please summarize below or attach a copy of your policy.

   ____

   ____

   ____

6. Does your agency have a formal policy on the conditions under which direct left-turn access to intersections or driveways is replaced by indirect left-turn treatments (e.g., jughandle roadways before a crossroad, loop roadways beyond a crossroad, directional median openings beyond a crossroad, right turns followed by U-turns)? .... ☐Yes ☐No

   If YES, please summarize below or attach a copy of your policy.

   ____

   ____

   ____

7. What are your geometric design criteria for median openings? Please attach a copy of any policy that differs from the AASHTO *Green Book*.

   ____

   ____

   ____

8. Does your agency have a formal policy on the use of raised medians vs. continuous two-way left-turn lanes? .... ☐Yes ☐No

   If YES, please attach a copy of your policy.

U-TURNS

9. Does your agency's policy for designing and locating median openings make specific reference to consideration of U-turn maneuvers? .... ☐Yes ☐No

   If YES, please attach a copy of your policy.

10. Are U-turns generally permitted at median openings operated by your agency?

    On rural (divided) highways? .... ☐Yes ☐No
    On urban/suburban arterials? .... ☐Yes ☐No
    At unsignalized median openings?.. ☐Yes ☐No
    At signalized median openings? .... ☐Yes ☐No

11. Does your agency have a formal policy concerning when to prohibit U-turns at median openings?.. ☐Yes ☐No

    Please summarize below or attach a copy of your policy.

    ____

    ____

    ____

12. What median and roadway widths are required by your agency to provide for U-turns at UNSIGNALIZED locations? Please attach a copy of any policy that differs from the AASHTO *Green Book*.

    ____

    ____

13. Has your agency experienced an increase in the number of U-turning vehicles when you install a nontraversable median? .... ☐Yes ☐No

14. Where median openings for making U-turn maneuvers were installed at unsignalized locations, what provisions (if any) were made for school buses, other buses, and/or large trucks?

    ____

    ____

15. What is your agency's traffic volume threshold to signalizing a median U-turn? .
    .... ☐Yes ☐No

EFFECTIVENESS

16. Has your agency encountered any safety or operational problems at unsignalized median openings? .... ☐Yes ☐No

    If YES, please describe the problems encountered and the types of locations at which the problems occurred.

    ____

    ____

    ____

    Were these problems related to any of the following factors?

    frequency/density of openings? .... ☐Yes ☐No
    median opening too long? .... ☐Yes ☐No
    opening in intersection functional area? .... ☐Yes ☐No
    opening across from right-turn lane? .... ☐Yes ☐No
    opening across left-turn lane? .... ☐Yes ☐No
    operational considerations (e.g. heavy U-turn or through volumes, trucks, etc)? .... ☐Yes ☐No
    roadway too narrow? .... ☐Yes ☐No
    median too narrow? .... ☐Yes ☐No
    median too wide? .... ☐Yes ☐No
    insufficient sight distance? .... ☐Yes ☐No
    driveway nearby? .... ☐Yes ☐No
    roadway geometry? .... ☐Yes ☐No
    inconsistent application? .... ☐Yes ☐No

17. Has your agency constructed any improvement projects intended specifically to mitigate the operational and safety problems at unsignalized median openings identified above? .... ☐Yes ☐No

    If YES, what was done and how effective was the project?

    ____

    ____

    ____

    Has any formal before-after evaluation of such projects been conducted?
    .... ☐Yes ☐No

18. Which of the following types of median openings are found on roads under the jurisdiction of your agency that might be suitable candidates for accident and field evaluations later in this study?

urban .... ☐Yes ☐No
rural .... ☐Yes ☐No
wide median .... ☐Yes ☐No
narrow median .... ☐Yes ☐No
signalized .... ☐Yes ☐No
unsignalized .... ☐Yes ☐No
full movement .... ☐Yes ☐No
directional (variations) .... ☐Yes ☐No

19. Has your agency implemented projects within the last 5 to 7 years in which a raised median was installed which eliminated direct left-turn access to one or more intersections or driveways and resulted in increased U-turn volumes at median openings elsewhere on the same roadway? .... ☐Yes ☐No

If YES, approximately how many projects of this type may have been implemented?

____

Have any operational or safety problems related to U-turn maneuvers been encountered in conjunction with such projects? .... ☐Yes ☐No

Please elaborate as necessary.________________________________

____

____

Has any formal before-after evaluation of such projects been conducted by your agency? .... ☐Yes ☐No

Would these projects be suitable for evaluation as part of this research?
.... ☐Yes ☐No

20. Has your agency implemented projects within the last 5 to 7 years in which an existing unsignalized median opening was closed, eliminating direct left-turn access to an intersection or driveway and resulting in increased U-turn volumes at median openings elsewhere on the same roadway? .... ☐Yes ☐No

If YES, approximately how many projects of this type may have been implemented?

____

Have any operational or safety problems been encountered in conjunction with such projects? .... ☐Yes ☐No

Please elaborate as necessary. ____

____

____

Has any formal before-after evaluation of such projects been conducted by your agency? .... ☐Yes ☐No

Would these projects be suitable for evaluation as part of this research? .... ☐Yes ☐No

21. Do you have any other observations or comments?

____

____

____

22. May we have the name of an engineer in your agency that we may contact to clarify any aspect of your response or to obtain additional information?

Contact: ____

Title: ____

Address: ____

____

Telephone #: ____

Fax #: ____

e-mail address: ____

Please return the completed survey by **July 31, 2001**, to:

Ingrid B. Potts, P.E.
Senior Traffic Engineer
Midwest Research Institute
425 Volker Blvd.
Kansas City, MO 64110

APPENDIX B

SUMMARY OF SURVEY RESPONSES FROM STATE AND LOCAL HIGHWAY AGENCIES

This appendix presents a summary of the responses to the survey questionnaire sent to state and local highway agencies concerning median openings at unsignalized intersections. The questionnaire addresses highway agency policies concerning location and design of median openings, treatment of U-turns at median openings, traffic operational and safety problems at median openings, and effectiveness of various mitigation measures. Appendix A presents the questionnaire that was used to conduct the survey.

SURVEY RECIPIENTS

The mailing list for the survey included:

- 50 state highway agencies and
- 109 local highway agencies (94 cities and 15 counties).

Thus, a total of 159 survey questionnaires were mailed.

The questionnaires for state highway agencies were generally sent to the state traffic engineer. The names and addresses of the state traffic engineers were determined from the membership roster of the AASHTO directory.

Most of the local highway agency engineers on the mailing list for the questionnaires were obtained from the AASHTO directory. The local agencies include approximately two major cities from each state and 15 selected urban or suburban counties. Rural counties were not surveyed because they are unlikely to operate many divided highways.

RESPONSE RATE

Table B-1 summarizes the responses to the median opening survey. A total of 65 responses were received out of the 159 questionnaires that were mailed. The responses received included 35 state agencies, 23 cities, and 7 counties. The overall response rate was 41 percent, including a response rate of 70 percent for state highway agencies and 28 percent for local highway agencies. Table B-2 presents a list of the state and local highway agencies that responded to this survey.

SUMMARY OF SURVEY RESPONSES

The highway agency responses to each question in the survey are summarized below. Where appropriate, the responses are tabulated. Highway agencies responded to survey questions in a mixture of metric and U.S. customary units. In this appendix, the units of measurement used in presenting each response are those actually used by the respondents.

Question 1—Criteria Used to Determine Location of Median Opening

In Question 1, highway agencies were asked about the criteria they use to determine the location of median openings. The general types of policies used by the responding agencies to determine the location of median openings are summarized in Table B-3. The types of policies used by the responding agencies include: AASHTO policy, state or local design policy, state or local access management policy, general guidelines (lists of factors considered as an informal policy), and engineering judgment. Because of multiple responses by some agencies, the totals add to more than 100 percent. The responses indicate that about half of the responding agencies have formal policies concerning median opening location and about half have guidelines or informal policies.

Table B-4 presents a list of the factors considered by highway agencies in determining the location of median openings. The factors were identified from the highway agency responses to the questionnaire and from the formal and informal policies that the state and local agencies submitted with their responses. The factors shown in Table B-4 are presented in decreasing order of the frequency with which they were mentioned. Factors mentioned by some highway agencies may, in fact, be considered by others; however, the table shows only those factors identified in the survey response and accompanying materials. The responses in Table B-4 add up to more than the number of agencies responding because many agencies provided multiple responses.

The three most commonly cited factors considered in determining the location of median openings were: proximity to other median openings, traffic volumes, and locations and functional classes of public road intersections. Other frequently mentioned factors included sight distance, operational efficiency, safety, area type, speed, availability of sufficient length to accommodate left-turn lanes, and median width.

Question 2—Types of Median Openings

Highway agencies were asked about the types of median openings that they use. All agencies stated that they use conventional (i.e., nondirectional) median openings on divided highways. Table B-5 presents the number and percentage of state and local agencies that use directional median openings,

TABLE B-1 Response rate for the highway agency survey

Agency type	Number of questionnaires mailed	Number of responses received	Response rate (%)
State agencies	50	35	70.0
Local agencies	109	30	27.6
Total	159	65	40.9

classified by relative frequency of usage. Most of the agencies use directional median openings either frequently or occasionally. Ten agencies stated that they typically use conventional median openings but that they occasionally use directional median openings. Nine agencies stated that they do not use directional median openings.

Question 3—Minimum Spacing Between Median Openings

Table B-6 summarizes the number and percentage of state and local agencies that have formal policies concerning the minimum spacing between median openings. Approximately 55 percent of the state agencies have formal policies, while only 45 percent of the local agencies have such policies. Of the 12 local agencies that have formal policies for minimum spacing between median openings, seven were cities and five were counties.

Table B-7 summarizes the number and percentage of state and local areas that have policies on spacing between median openings that differ between rural and urban areas. The tabulation of local agencies in this table does not include cities, because cities do not typically include rural areas. Among the 22 states that have formal policies on spacings between median openings, 16 states have different policies for rural and urban areas, while six do not. Of the five county agencies that

TABLE B-2 List of highway agencies that responded to survey

State highway agencies	Local highway agencies
Alabama	City of Mobile, AL
Alaska	Borough of Matanuska-Susitna, AK
Arizona	City of El Cajon, CA
California	City of San Diego, CA
Connecticut	City of Loveland, CO
Florida	City of Albany, GA
Georgia	City of Peoria, IL
Idaho	City of Ann Arbor, MI
Illinois	City of Kansas City, MO
Iowa	City of Springfield, MO
Kansas	City of Henderson, NV
Louisiana	City of Concord, NH
Massachusetts	City of Newark, NJ
Michigan	City of Bismarck, ND
Mississippi	City of Fargo, ND
Missouri	City of Columbus, OH
Nebraska	City of Norman, OK
Nevada	City of Charleston, SC
New Hampshire	City of Nashville, TN
New Mexico	City of Houston, TX
New York	City of St. George, UT
North Carolina	City of Lynchburg, VA
North Dakota	Maricopa County, AZ
Ohio	Pima County, AZ
Oklahoma	Riverside County, CA
Oregon	Broward County, FL
Pennsylvania	Osceola County, FL
Rhode Island	Monroe County, NY
South Carolina	Fairfax County, VA
Texas	
Utah	
Virginia	
West Virginia	
Wisconsin	
Wyoming	

TABLE B-3 General policy used to determine where to allow median openings

Policy used to determine location of median opening	Number (percentage) of agencies					
	State agencies		Local agencies		Total	
AASHTO policy	3	(9.7)	3	(12.0)	6	(10.7)
State or local design policy	4	(12.9)	9	(36.0)	13	(23.2)
State or local access management policy	6	(19.3)	4	(16.0)	10	(17.9)
General guidelines, list of factors considered, or informal policy	17	(54.8)	13	(52.0)	30	(53.6)
Engineering judgment	6	(19.3)	4	(16.0)	10	(17.9)
Total number of agencies responding	31		25		56	

TABLE B-4 Factors considered in determining the location of median openings

Factors considered	State agencies	Local agencies	Total
Proximity to other median openings	15	11	26
Traffic volumes (particularly minor-road volumes)	12	13	25
Locations and functional classes of public road intersections	12	12	24
Sight distance	11	1	12
Operational efficiency	6	3	9
Safety	4	4	8
Area type (rural/suburban/urban)	5	2	7
Speed	3	4	7
Availability of sufficient length for left-turn lane	4	2	6
Median width	5	0	5
Truck volumes	2	1	3
Practicality of frontage roads	3	0	3
Grade within the median	2	1	3
Proximity to driveways	1	1	2
Emergency vehicle access needs	1	1	2
Parcel size/land use	0	2	2
Willingness of developer to pay cost of median opening	1	1	2
Location of current or future signalized intersections	2	0	2
Type of facility	1	0	1
Older drivers	1	0	1
Natural barriers	1	0	1
Roadway environment	1	0	1

TABLE B-5 Highway agency use of directional median openings

Agency type	Number (percentage) of agencies that use directional median openings						
	Frequently		Occasionally		Not used		Total
State agencies	14	(51.9)	7	(25.9)	6	(22.2)	27
Local agencies	20	(77.0)	3	(11.5)	3	(11.5)	26
Total	34	(64.2)	10	(18.9)	9	(16.9)	53

TABLE B-6 Number of agencies that have a policy concerning minimum spacing between median openings

Agency type	Number (percentage) of agencies that have formal policies concerning minimum spacing between median openings		
	Yes	No	Total
State agencies	22 (64.7)	12 (35.3)	34
Local agencies	12 (42.9)	16 (57.1)	28
Total	34 (54.8)	28 (45.2)	62

TABLE B-7 Number of agencies that have different policies on median opening spacing for rural and urban areas

Agency type	Number (percentage) of agencies that have different policies concerning minimum spacing between median openings for rural and urban areas		
	Yes	No	Total
State agencies	16 (72.7)	6 (27.3)	22
Local agencies[a]	1 (20.0)	4 (80.0)	5
Total	17 (63.0)	10 (37.0)	27

[a] County agencies only.

have policies on spacing between median openings, only one has a policy that distinguishes between rural and urban areas.

Table B-8 presents median opening spacing policies of state highway agencies that had numerical spacing policies that could be easily summarized. Some agencies had policies that were based on more variable criteria such as left-turn queue lengths, sight distance, and traffic volumes, which are harder to summarize and are not included in Table B-8. Comparable data for local agencies are presented in Table B-9. In response to this question, some agencies presented policies on minimum driveway or access-point spacing. These policies are not included in the tables because there is not necessarily a median opening at every driveway or access point.

It can be seen in Table B-8 that the states that have different spacing policies for rural and urban areas typically require higher median-opening spacings in rural areas than in urban areas. The values reported for minimum median opening spacing for rural areas varied from 150 to 800 m (500 to 2,640 ft), while the comparable minimum spacing for urban areas varied from 90 to 800 m (300 to 2,640 ft); however, the average minimum median opening spacing was 430 m (1,400 ft) in rural areas and 270 m (880 ft) in urban areas. Four state agencies stated desirable (rather than minimum) values for median opening spacing. Georgia also presented a maximum spacing policy for median openings (5,200 ft for rural areas and 1,320 ft in urban areas).

Table B-9 presents the minimum spacings between median openings for the five cities and five counties that presented quantitative minimum median spacing values in response to the survey. The general trend of higher minimum median opening spacing at rural areas was still present, although the differences in median opening spacing between area types are not as large as those shown in Table B-8. All of the cities shown in the table had criteria for urban areas only. Only one county (Osceola County, FL), had policies on median opening spacing that differed between urban and rural areas. This county stated that they use the access management policy of their state DOT.

Question 4—Location of Unsignalized Median Openings

Question 4 asked highway agencies about their policies for location of unsignalized median openings. The answers received did not differ substantially from the responses presented above in Tables B-3, B-4, B-8, and B-9. Table B-10 summarizes the number and percentage of agencies that indicated whether they had a formal policy concerning the location of unsignalized median openings.

Two states attached their specific policies on sight distance for unsignalized median opening locations; these policies are summarized in Table B-11. New Mexico has minimum criteria for sight distance along the main road at intersections based on the posted speed and Virginia has minimum criteria based on the design speed.

Question 5—Installation of Left-Turn Lanes at Unsignalized Median Openings

Question 5 asks highway agencies about their criteria for installation of left-turn lanes at unsignalized median openings. A majority of the responding agencies require installation of left-turn lanes at unsignalized median openings in all or most cases. Table B-12 presents the number and percentage of agencies that require left-turn lanes. Sixteen of the 42 agencies that require left-turn lanes at unsignalized median openings stated that left-turn lanes are provided only where specific warrants are met; other agencies may have explicit warrants for left-turn lanes, as well. Most respondents indicated that their warrants were based on left-turn volumes. Two states presented volume

TABLE B-8 State policies on minimum spacing between median openings

State	Minimum spacing (ft) Rural	Minimum spacing (ft) Urban	Comments
Alabama	600	300	
Arizona	1,320	660	For businesses generating high traffic volumes the minimum spacing is 330 ft
California	1,640	1,640	Unsure of possible differences between rural and urban criteria
Florida	1,320 2,640	330-660 660-1,320	Directional Conventional
Georgia	1,320	660	Maximum spacing 5,200 ft in rural areas and 1,320 ft in urban areas
Iowa	1,000	660	
Idaho	1,312	660	
Illinois	2,625 (minimum) 5,250 (desirable)	1,312	Longer minimum spacing used if needed to accommodate left turn lanes
Louisiana	1,500	500	
Maine	–	1,312-1,640 (minor arterial) 1,640-1,968 (major arterial)	Criteria apply to signalized median openings only
Michigan	1,320	660	Desirable spacing
Mississippi	1,760	880	
North Carolina	1,500	700 (< 45 mph) 1,000 (45-55 mph)	Urban spacing criteria vary with operating speed
Nebraska	1,000 (minimum) 2,000 (desirable)	600	
New Mexico	600	300	
Nevada	660	–	In urban areas, have criteria for access spacing rather than median opening spacing
Ohio	–	–	Have spacing criteria for driveways but not for median openings
Oklahoma	2,640 (minimum) 5,280 (desirable)	1,320	Longer minimum spacing used if needed to accommodate left turn lanes
Pennsylvania	1,500	1,500	
South Carolina	1,000	500	
Texas	1,320 – 2,640	1,320 – 2,640	
Virginia	700-1,000 (35-45 mph) 500-650 (50-70 mph)	700–1,000 (35-45 mph) 500–650 (50-70 mph)	Urban spacing criteria vary with design speed
Range	500 – 2,640	300 – 2,640	
Average	1,400	880	

warrants for left-turn lanes at unsignalized median openings based on research by Harmelink (*67*).

Question 6—Use of Indirect Left-Turn Treatments

Question 6 asked highway agencies about their use of indirect left-turn treatments. Only two state agencies responded that they have a formal policy on the conditions under which direct left-turn access to intersections or driveways is replaced by indirect left-turn treatment. The research team is aware of one other state highway agency which did not respond to the survey, which clearly would have answered "Yes" to Question 6 had they responded. Table B-13 presents a summary of the state and local agency responses concerning use of indirect left-turn treatments.

TABLE B-9 Local agency policies on minimum median opening spacing

County	Minimum spacing (ft) Rural	Minimum spacing (ft) Urban	Comments
San Diego, CA	–	600	
Springfield, MO	–	500	
Fargo, ND	–	600 (arterials) 300 (collectors)	
Concord, NH	–	500 (commercial) 1,000 (suburban)	For arterials and collectors
Henderson, NV	–	660	
Maricopa County, AZ	660	660	For arterials and collectors
Pima County, AZ	1,320	1,320	
Riverside County, CA	330-1,320	330-1,320	Based on intersection spacing
Osceola County, FL	1,320 2,640	330-660 660-1,320	Directional Conventional
Broward County, FL	660	660	
Range	660 – 2,640	330 – 1,320	
Average	800	725	

TABLE B-10 Formal policies on location of unsignalized median openings

Agency type	Number (percentage) of agencies that have formal policies concerning location of unsignalized median openings: Yes	No	Total
State agencies	15 (45.5)	18 (54.5)	33
Local agencies	9 (33.3)	18 (66.7)	27
Total	24 (40.0)	36 (60.0)	60

TABLE B-11 Minimum sight distance (ft) along the major road for median openings

State agency	Speed (mph) 30	35	40	45	50	55	60	65	70
New Mexico (based on posted speed)	200	250	325	400	475	550	650	725	–
Virginia (based on design speed)	–	400	475	525	600	650	700	–	825

TABLE B-12 Number of agencies that require left-turn lanes at unsignalized median openings

Agency type	Number (percentage) of agencies that require left-turn lanes at unsignalized median openings: Yes[a]	No	Total
State agencies	24 (75.0)	8 (25.0)	32
Local agencies	18 (64.3)	10 (35.7)	28
Total	42 (70.0)	18 (30.0)	60

[a] In many cases, left-turn lanes are required only if specific volume warrants are met.

TABLE B-13 Number of agencies with formal policies on the use of indirect left-turn treatments as an alternative to direct left-turn access

Agency type	Number (percentage) of agencies that have formal policies on the use of indirect left-turn treatments: Yes	No	Total
State agencies	2 (6.1)	31 (93.9)	33
Local agencies	0 (0.0)	28 (100.0)	28
Total	2 (3.3)	59 (96.70)	61

Question 7—Geometric Design Criteria for Median Openings

Question 7 asked respondents whether they had geometric design criteria for median openings and if their policy differed from the AASHTO *Green Book*. Fifteen highway agencies (13 state agencies and two local agencies) provided copies of their geometric design policies in response to Question 7.

The types of policies that the responding agencies indicated they used for geometric design of median openings were: AASHTO policy; state or local geometric design policies; state or local access management policy; general guidelines (list of factors considered as informal policies); and engineering judgment. Table B-14 summarizes the number of state and local agencies that use each of these policy types. Because of multiple responses by some agencies, the totals add to more than 100 percent.

Most of the state and local agencies (approximately 70 percent) use AASHTO policies for geometric design of median openings; in many cases, these are supplemented by general guidelines, list of factors considered, or informal policies.

Question 8—Raised Medians vs. Continuous Two-Way Left-Turn Lanes

Question 8 asked respondents whether they had a formal policy on the use of raised medians versus continuous two-way left-turn lanes (TWLTLs). Table B-15 summarizes the number and percentage of state and local agencies that have such a policy. Most of the responding agencies (81 percent) do not have such a policy.

Eleven of the 58 responding agencies provided copies of their policy on the use of raised medians versus continuous TWLTLs. The following sections on location, speed, lane width, and intersections summarize key elements of the highway agency policies that those agencies noted in their responses.

Location

- A TWLTL may be considered in developed areas with frequent commercial roadside access and with no more than two through lanes in each direction.
- Any TWLTL must be clearly marked and adequately delineated (MUTCD).
- A TWLTL may be used where average daily through traffic volumes are 10,000 to 20,000 veh/day (4 lanes) or 5,000 to 12,000 veh/day (2 lanes), and left-turn volumes are at least 70 midblock turns per 300 m during peak hour. High left-turning volumes combined with high ADT could possibly lead to operational and safety problems. Providing a raised median, with left turn and/or U-turn lanes should also be considered.
- In areas where there are numerous access points along an existing roadway, continuous TWLTLs may increase mobility and reduce conflicts. This design may be considered in suburban areas where there are numerous existing access points and where other solutions to control access cannot be implemented.
- Flush/traversable medians may be used in both the urban and suburban areas in conjunction with curb and gutter along the outside edges of the traveled way. For most applications, the flush TWLTL should be used. However, in larger metropolitan areas, a traversable TWLTL may be used.

TABLE B-14 Type of policy used for geometric design of median openings

Policy used for geometric design of median openings	State agencies		Local agencies		Total	
AASHTO policy	19	(67.9)	16	(76.2)	35	(71.4)
State or local design policy	3	(10.7)	3	(14.3)	6	(12.2)
State or local access management policy	5	(17.9)	1	(4.8)	6	(12.2)
General guidelines, list of factors considered or informal policy	13	(46.4)	6	(28.6)	19	(38.8)
Engineering judgment	1	(3.6)	0	(0.0)	1	(2.0)
Total number of agencies responding	28		21		49	

TABLE B-15 Policy on the use of raised medians versus continuous two-way left-turn lanes

Agency type	Number (percentage) of agencies that have formal policies on the use of raised medians vs. continuous two-way left-turn lanes				
	Yes		No		Total
State agencies	8	(26.7)	22	(73.3)	30
Local agencies	3	(10.7)	25	(89.3)	28
Total	11	(19.0)	47	(81.0)	58

- TWLTLs shall only be used with roadways having a maximum of two through lanes in each direction of travel (i.e., seven-lane TWLTLs are not used).
- Continuous TWLTLs are primarily used on urban highways.
- Continuous TWLTLs are primarily used on minor arterials.
- Major street plan calls for continuous TWLTLs on all new urban arterials.

Speed

- A TWLTL is limited to arterials with operating speeds of 70 km/hr or less.
- Continuous TWLTLs may be considered on urban, two-lane state highways with a posted speed of 45 mph or less. Where the posted speed is greater than 45 mph, placement of a nontraversable median should be considered.
- Continuous TWLTLs should be considered on low-speed arterial highways (25 to 45 mph) with no heavy concentrations of left-turn traffic. They also may be used where an arterial or major route must pass through a developed area having numerous street and driveway intersections and where it is impractical to limit left turns.
- In commercial and industrial areas where property values are high and rights-of-way for wide medians are difficult to acquire, a paved flush traversable median 10- to 16-ft wide is the optimum design.
- All arterials with design speeds or posted speeds ≥ 45 mph, base year traffic volumes ≤ 18,000 veh/day, and design year traffic volumes ≤ 24,000 veh/day will require a five-lane section (flush median).
- All arterials with design speeds or posted speeds ≤ 45 mph and base year traffic volume ≤ 18,000 veh/day and design year traffic volume ≥ 24,000 veh/day will require a five-lane section (flush median). The project will be designed to incorporate a future 20-ft raised median. Right-of-way will be purchased for footprint determined by the 20-ft median typical section. Monitoring of accidents and traffic volumes on a five-year cycle by the Safety Engineer in the Office of Traffic Operations will determine the need and implementation of a raised median section.
- All urban arterials with base year traffic volumes ≥ 18,000 veh/day, design year traffic volumes ≥ 24,000 veh/day, and design speed ≤ 45 mph will have a 20-ft raised median.
- All arterials with posted speeds ≥ 55 mph or design speeds ≥ 50 mph will require the design of a 44-ft depressed median or a positive barrier system.

Lane Width

- The preferred lane width is 4.5 m with a minimum lane width of 3.75 m.
- The usual design widths are 3.3 m, 3.6 m, or 4 m. There is some evidence that a wide TWLTL encourages drivers to place their vehicles in an angular rather than parallel turning position and thereby causes other vehicles to encroach on adjacent through lanes. Therefore, maximum widths for flush TWLTL medians should be 4 m.
- The minimum desirable width shall be 12 ft and the maximum 16 ft.
- The minimum width for a TWLTL shall be 3.6 m. The preferred width is 4.2 m. Wider TWLTLs are occasionally provided to conform with local agency standards. However, TWLTLs wider than 4.2 m are not recommended, and in no case should the width of a TWLTL exceed 4.8 m. Additional width may encourage drivers in opposite directions to use the TWLTL simultaneously.

Intersections

- At minor intersections, the TWLTL should be extended up to the intersection. At major or signalized intersections, the TWLTL should be terminated in advance of the intersection.
- Raised medians will be constructed on multilane facilities at intersections that include one of the following:
  - High turning volumes relating to 18,000 veh/day (base year) and 24,000 veh/day (design year)
  - Accident rate greater than the state average for its classification. Excessive queue lengths (as determined by District Traffic Engineer) in conjunction with excessive number of driveways.

Question 9—Consideration of U-Turn Maneuvers in Design and Location of Median Openings

Question 9 asked respondents whether their agency's policy for designing and locating median openings makes specific reference to U-turn maneuvers. Table B-16 presents the number and percentage of the state and local agencies that do consider U-turn maneuvers explicitly in their criteria. The responses indicate that only 16 percent of highway agencies have a formal policy on median opening design and location that considers U-turn maneuvers, while 84 percent of highway agencies do not have such a policy.

Six of the nine agencies that consider U-turn maneuvers in median opening design and location attached copies of their policy. Most of these agencies rely primarily on AASHTO geometric design policies or some variation of AASHTO policy in their own guidelines. One state agency adds 12 ft to the AASHTO guidance on median width to better accommodate U-turn maneuvers, while another adds between 11 and 17 ft to the median width depending on the design vehicle. The factors mentioned in the policies for U-turn maneuvers at unsignalized median openings include:

TABLE B-16 Number of highway agencies with policies that consider U-turn maneuvers in design and location of median openings

Agency type	Number (percentage) of agencies that make specific reference to U-turn maneuvers in policies for design and location of median openings				
	Yes		No		Total
State agencies	7	(22.6)	24	(77.4)	31
Local agencies	2	(7.7)	24	(92.3)	26
Total	9	(15.8)	48	(84.2)	57

- Median width (based on design vehicles and potential for encroachment) (six agencies)
- Traffic conditions including ADTs, truck volumes, and peak-hour turning movement counts (four agencies)
- Sight distance (two agencies)
- Ability to begin and end U-turn maneuvers on the inner lane next to the median (two agencies)
- Accident frequency, particularly angle and rear-end collisions involving left- or U-turning vehicles (one agency)
- Specific threshold accident history criteria, such as five or more left-turn or U-turn-related accidents per year, similar to MUTCD requirements (one agency)
- Location of the median openings with respect to signalized intersections (one agency)
- Presence of exclusive left-turn lanes (one agency)
- Availability of alternate locations for left- and U-turn maneuvers (one agency)

Question 10—Prohibition of U-Turn Maneuvers

Question 10 asked highway agencies whether U-turn maneuvers were permitted or not permitted at specific types of median openings. Table B-17 summarizes the responses to this question for rural and urban areas and for unsignalized and signalized median openings. Approximately 80 percent of the agencies that responded permit U-turns at all types of median openings. It should be noted that nine agencies (five states and four local agencies) generally prohibit U-turn maneuvers at unsignalized median openings.

Question 11—Criteria for U-Turn Prohibitions at Median Openings

Question 11 asked highway agencies whether they have formal policies on when to prohibit U-turn maneuvers at specific median openings. Most of the responding agencies (91 percent of states and 92 percent of local agencies) do have formal policies concerning when to prohibit U-turns at median openings. Table B-18 summarizes the highway agency responses to this question.

The agencies with formal policies prohibit U-turns in the following situations:

- At all signalized intersections that have a right-turn overlap phase from a side street approach on the left during the protected left-turn phase on the mainline roadway (one agency)

TABLE B-17 Number of highway agencies that permit U-turns at specific types of median openings

Agency type	Number (percentage) of agencies that permit U-turns at specific types of median openings				
	U-turns permitted		U-turns not permitted		Total
Median Openings on Rural Highways					
State agencies	26	(83.9)	5	(16.1)	31
Local agencies[a]	4	(100.0)	0	(0.0)	4
Total	30	(85.7)	5	(14.3)	35
Median Openings on Urban/Suburban Arterials					
State agencies	26	(83.9)	5	(16.1)	31
Local agencies	22	(84.6)	4	(15.4)	26
Total	48	(84.2)	9	(15.8)	57
Unsignalized Median Openings					
State agencies	26	(83.9)	5	(16.1)	31
Local agencies	22	(84.6)	4	(15.4)	26
Total	48	(84.2)	9	(15.8)	57
Signalized Median Openings					
State agencies	25	(80.6)	6	(19.4)	31
Local agencies	20	(76.9)	6	(23.1)	26
Total	45	(78.9)	12	(21.1)	57

[a] Includes county agencies only.

TABLE B-18 Number of agencies that have formal policies on when to prohibit U-turns at median openings

Agency type	Number (percentage) of agencies that have formal policy concerning when to prohibit U-turns at median openings				
	Yes		No		Total
State agencies	3	(9.4)	29	(90.6)	32
Local agencies	2	(7.7)	24	(92.3)	26
Total	5	(8.8)	53	(91.2)	58

- At any curve or on the approach to or near the crest of a grade where a U-turning vehicle cannot be seen by the driver of any other vehicle approaching from any direction within 500 ft. In addition, any left turn or U-turn at an intersection that does not meet the minimum sight distance criteria standards for U-turns as established by AASHTO (one agency)
- At intersections with a receiving pavement width of 24 ft or less and at which the average vehicle cannot execute a U-turn maneuver in a single continuous movement (one agency)
- At any location for which a review of accident history finds that a U-turn restriction should be implemented, possibly only for certain times of the day (one agency)
- Geometric design criteria (not further specified) (one agency)
- At signalized intersections (one agency)
- If less than 37 ft of width is available from the inside of the left-turn curb to the curb of the opposing lanes (one agency)

Two agencies stated that U-turns are prohibited at all median openings unless they are signed to permit U-turns.

Some agencies that did not have formal policies on where to permit or prohibit U-turns have informal guidelines that are presented below:

- U-turns are permitted only at locations having sufficient roadway width for maneuver (four agencies).
- U-turns are prohibited based on accident rate or safety problems (three agencies).
- U-turns are prohibited at signalized intersections where right-turn overlaps are allowed (two agencies).
- U-turns are prohibited where they would create a substantial number of conflicts (two agencies).
- U-turns are prohibited in some school zones (one agency).
- U-turns are prohibited to relieve congestion at median openings (one agency).
- U-turns are permitted at unsignalized median openings where a specific need is identified (one agency).

U-turns are prohibited where a need is identified through engineering judgment (one agency)

Question 12—Median and Roadway Widths Required to Provide for U-turns at Unsignalized Median Openings

Question 12 asked highway agencies about the median width required by their agencies to provide for U-turns at unsignalized median openings. Fifteen state and five local agencies (or 53 percent of the agencies responding) stated that they follow the AASHTO *Green Book* to determine the median and roadway widths required to provide for U-turns at unsignalized median openings. Specifically, these agencies use the median width policy shown in *Green Book* Exhibit 9-92. Five state and six local agencies (or 29 percent of the agencies responding) stated that they have no policy or use engineering judgment. Two state and five local agencies stated that they have specific policies that differ from AASHTO *Green Book*. These policies are summarized below:

- One state uses minimum median widths that are from 11 ft and 17 ft wider than those presented in the *Green Book*. Table B-19 presents the values used by this state agency.
- One state adds 12 ft to AASHTO median widths shown in the *Green Book*.
- One city permits U-turns on roads with 100-ft rights-of-way. This allows three travel lanes or 36 ft of traveled way width to receive traffic.
- One city establishes minimum median widths needs in the range of 10 to 20 ft based on the type of roadway.

TABLE B-19 Minimum median widths (ft) for U-turns used by one state highway agency

Type of maneuver	Type and length of design vehicle				
	P (19 ft)	SU (30 ft)	Bus (40 ft)	WB-50 (55 ft)	WB-60 (70 ft)
Left lane to inner lane	44	76	80	82	82
Left lane to 2nd lane	32	64	68	70	70
Left lane to 3rd lane	22	54	58	60	60

- One city allows U-turns on roads with a minimum width of six lanes that include turn lanes.
- One city permits U-turns on arterials with a minimum width of 42 ft, which includes a 4-ft separator, 33 ft of travel lane width, and 5 ft of bike lane width.
- One county stated that they permit U-turns with a median width of 14 ft and roadway width for one direction of travel of 26 ft.
- One county stated that they permit U-turns with a median width between 20 and 24 ft and directional roadway width between 30 and 36 ft for a four-lane divided highway.

Question 13—Increase in U-Turning Vehicle Volumes When a Nontraversable Median is Installed

Question 13 asked highway agencies whether they had experienced an increase in the volume of U-turning vehicles when a nontraversable median was installed. Most agencies (79 percent) responded that they had experienced an increase. Table B-20 summarizes the responses to this question.

Question 14—Provision for School Buses, Other Buses, and/or Large Trucks

Question 14 asked highway agencies whether their criteria for design of median openings included provisions for school buses, other buses, and/or large trucks. Table B-21 summarizes the responses to Question 14. Approximately half of the responding state agencies indicated that they made provisions for U-turns by large vehicles at unsignalized median openings. Only one local agency stated that they had made such a provision.

Question 15—Traffic Volume Threshold to Signalizing a Median Opening

Question 15 asked highway agencies whether they had any established traffic volume thresholds or other established criteria for signalizing median openings that differed from the general MUTCD warrants for signalizing intersections. None of the responding agencies presented any criteria for signalizing median openings that differ from MUTCD signal warrants.

Question 16—Safety or Operational Problems at Unsignalized Median Openings

Question 16 asked highway agencies whether they had experienced safety or traffic operational problems at unsignalized median openings. Table B-22 shows the number and percentage of highway agencies that indicated that they had experienced such problems at unsignalized median openings. Twenty-nine out of the 49 agencies that responded to this question (59 percent) indicated that they have encountered

TABLE B-20 Number of agencies that have experienced an increase in U-turn volumes when a nontraversable median is installed

Agency type	Number (percentage) of agencies that experienced an increase in U-turn volumes when a nontraversable median is installed		
	Yes	No	Total
State agencies	11 (73.3)	4 (26.7)	15
Local agencies	15 (83.3)	3 (16.7)	18
Total	26 (78.8)	7 (21.2)	33

TABLE B-21 Number of agencies that make provisions for school buses, other buses, and large trucks in design of unsignalized median openings

Agency type	Number (percentage) of agencies that make provision for school buses, other buses, or large trucks in design of median openings		
	Yes	No	Total
State agencies	10 (52.6)	9 (47.4)	19
Local agencies	1 (5.9)	16 (94.1)	17
Total	11 (30.6)	25 (69.4)	36

TABLE B-22 Number of agencies that have encountered safety or operational problems at unsignalized median openings

Agency type	Number (percentage) of agencies that have encountered safety or operational problems at unsignalized median openings		
	Yes	No	Total
State agencies	12 (48.0)	13 (52.0)	25
Local agencies	17 (70.8)	7 (29.2)	24
Total	29 (59.2)	20 (40.8)	49

safety or operational problems at unsignalized median openings. Table B-23 presents factors that the responding agencies indicated were related to the safety or operational problems they encountered.

Based on Table B-23, the five most cited factors that are related to safety or operational problems at unsignalized median openings in decreasing order are:

- Operational considerations (e.g., heavy U-turns or through volumes, trucks, etc)
- Median too narrow
- Driveway nearby
- Poor roadway geometry
- Roadway too narrow

All factors presented in Table B-23 were cited by eight or more agencies as contributing to safety or operational problems at unsignalized median openings. Some additional factors cited by the agencies include:

- High speed on approaches to median opening (one agency)
- Excessive number of conflict points for crossing traffic (one agency)
- High number of accidents at median opening when roadway was converted from a two-lane to a four-lane facility (one agency)

Question 17—Mitigation of Safety and Operational Problems at Unsignalized Median Openings

Question 17 asked highway agencies about mitigation measures they had used in response to safety and operational problems at unsignalized median openings. Table B-24 presents the number and percentage of agencies that have constructed improvement projects intended to mitigate safety and operational problems at unsignalized median openings. Thirty-seven percent of the agencies stated that they had constructed such improvements.

Some of the mitigation measures for safety and operational problems cited are presented below:

- Removal of closely spaced median openings by replacing raised medians with TWLTLs (four agencies)
- Replacement of conventional crossovers with directional crossovers (two agencies)

TABLE B-23 Factors identified by highway agencies as related to the safety or operational problems they encountered at unsignalized median openings

Factors related to safety or operational problems	Number of agencies					
	State agencies		Local agencies		Total	
	Yes	No	Yes	No	Yes	No
Operational considerations (congestion, trucks)	10	0	10	7	20	7
Median too narrow	10	1	6	10	16	11
Driveway nearby	6	3	10	8	16	11
Poor roadway geometry	8	1	7	9	15	10
Roadway too narrow	8	3	6	11	14	14
Median opening within the functional area of an intersection	5	4	7	8	12	12
Insufficient sight distance	6	3	5	10	11	13
Frequency/density of median openings	4	6	6	9	10	15
Median opening across from right-turn lane	3	7	1	14	4	21
Median opening too long	5	5	4	11	9	16
Median opening within left-turn lane	4	5	4	12	8	17
Inconsistent application	4	5	5	9	9	14
Median too wide	4	6	4	11	8	17

TABLE B-24 Number of agencies that have constructed improvement projects to mitigate safety or operational problems at unsignalized median openings

Agency type	Number (percentage) of agencies that have constructed improvement projects to mitigate safety and operational problems at unsignalized median openings		
	Yes	No	Total
State agencies	13 (44.8)	16 (55.2)	29
Local agencies	8 (29.6)	19 (70.4)	27
Total	21 (37.5)	35 (62.5)	56

- Installation of left-turn storage lanes (two agencies)
- Installation of left-turn lanes with positive offset (two agencies)
- Signalize intersection (two agencies)
- Close median openings to allow left turns to align properly (one agency)
- Reconfigure median openings by channelizing or adding left-turn lanes to prevent congestion or confusion in the median opening (one agency)
- Installation of directional median openings to permit left turns from the major-road left-turn lane, but prohibit left turns and through movements from the minor road (one agency)
- Provide a median opening at what formerly was a right-in/right-out driveway (one agency)
- Eliminate conventional median openings and replace with jughandle U-turns (one agency)
- Installation of "No U-turn" signs (one agency)
- Installation of raised/extended median to prevent U-turns (one agency)

Table B-25 presents the number and percentage of agencies that have conducted formal before-after evaluations of improvement projects that were constructed to mitigate the safety and operational problems at unsignalized median openings. Six agencies indicated that they have performed such evaluations.

Question 18—Suitable Candidate Sites for Accident and Field Evaluations

In Question 18, highway agencies were asked to identify types of median openings under their jurisdiction and that might be suitable candidates for accident and field evaluation later in this research. Table B-26 identifies the types of median openings that were identified by responding agencies as potentially available for evaluation.

Question 19—Increase in U-Turn Volumes at Adjacent Median Openings Caused by the Installation of Raised Medians to Eliminate Direct Left-Turn Access to Intersections or Driveways

In Question 19, highway agencies were asked whether they had experienced increases in U-turn volumes at median openings, as a result of projects in which a raised median that eliminated direct left-turn access to one or more intersections or driveways was installed. Table B-27 shows that more than half of the responding agencies indicated that they had implemented such projects recently (during the last 5 to 7 years) in their jurisdiction. Ten state and 15 local agencies estimated the approximate number of such projects; these estimates are presented in Table B-28.

Table B-29 presents the number and percentage of state and local agencies that encountered safety or operational problems related to the installation of raised medians. Only three agencies indicated that they had encountered such safety or operational problems. Only one agency stated the type of problem which was that a small number of drivers made illegal U-turns or mounted the median to cross it.

The state and local agencies were asked if they have performed any formal before-after evaluation of projects in which a raised median was installed which eliminated direct left-turn access to intersection or driveways. Table B-30 summarizes the responses to this question. Only one state indicated

TABLE B-25 Number of agencies that have performed formal before-after evaluations of improvement projects at unsignalized median openings

Agency type	Number (percentage) of agencies that have conducted evaluations of improvement projects intended to mitigate the safety and operational problems at unsignalized median openings				
	Yes		No		Total
State agencies	4	(14.3)	24	(85.7)	28
Local agencies	2	(7.4)	25	(92.6)	27
Total	6	(10.9)	49	(89.1)	55

TABLE B-26 Types of median openings that might be suitable candidates for accident and field evaluation

Types of median openings that might be suitable candidates for evaluation	Number of agencies					
	State agencies		Local agencies		Total	
	Yes	No	Yes	No	Yes	No
Urban	17	5	19	3	36	8
Rural	20	3	4	13	24	16
Wide median	14	7	9	11	23	18
Narrow median	18	3	11	8	29	11
Signalized	10	8	15	6	25	14
Unsignalized	18	3	18	4	36	7
Conventional (full movement)	18	3	17	4	35	7
Directional	12	8	13	6	25	14

TABLE B-27 Number of agencies that experienced an increase in U-turn volumes at median openings when raised medians were installed which eliminated direct left-turn access to intersection or driveways

Agency type	Number (percentage) of agencies that have recently implemented projects in which a raised median was installed to eliminate direct left-turn access to intersection or driveways and resulted in increased U-turn volumes at median openings elsewhere				
	Yes		No		Total
State agencies	14	(46.7)	16	(53.3)	30
Local agencies	16	(61.5)	10	(38.5)	26
Total	30	(53.6)	26	(46.4)	56

TABLE B-28 Number of agencies and estimated number of projects that installed raised median and eliminated direct left-turn access to intersections and driveways resulting in an increase in U-turn volumes at adjacent median openings

Agency type	Number of agencies	Total number of projects	Average number of projects per agency
State agencies	9	107	12
Local agencies	15	32	2
Total	24	139	7

TABLE B-29 Number of agencies that experienced safety or operational problems related to the increased U-turn maneuvers resulting from installation of raised medians

Agency type	Number (percentage) of agencies that experienced safety or operational problems related to U-turn maneuvers in conjunction with projects in which a raised median was installed				
	Yes		No		Total
State agencies	0	(0.0)	19	(100.0)	19
Local agencies	3	(14.3)	18	(85.7)	21
Total	3	(7.5)	37	(92.5)	40

TABLE B-30 Number of agencies that have performed formal before-after evaluations of projects involving raised medians

Agency type	Number (percentage) of agencies that have performed formal before-after evaluations of projects in which a raised median was installed and direct left-turn access to intersection or driveways was eliminated				
	Yes		No		Total
State agencies	1	(3.4)	28	(96.6)	29
Local agencies	0	(0.0)	22	(100.0)	22
Total	1	(2.0)	50	(98.0)	51

that they had performed such an evaluation. Table B-31 presents the number of state and local agencies that indicated that they have projects that may potentially be suitable for evaluation as part of this research. A total of 13 agencies (four state and nine local agencies) responded that they had potentially suitable projects available.

Question 20—Closing of Existing Unsignalized Median Opening Resulting in Increased U-Turn Volumes at Median Openings Elsewhere on the Same Roadway

Question 20 asked highway agencies whether they had implemented projects in which existing unsignalized median openings were closed eliminating direct left-turn access to one or more intersections or driveways, and resulting in increased U-turn volumes at median openings elsewhere on the same roadway. The responses to this question are summarized in Table B-32. Thirty-seven percent of the agencies indicated that they had implemented such projects recently (during the last 5 to 7 years) in their jurisdiction. Eleven agencies estimated the approximate number of such projects; these estimates are summarized in Table B-33.

Table B-34 shows the number of agencies that had experienced safety or operational problems resulting from projects in which an existing unsignalized median opening was closed. It can be seen in the Table B-34 that only one state answered that it had encountered such problems; this agency

TABLE B-31 Number of agencies that indicated they have projects involving installation of raised medians that are potentially suitable for evaluation as part of this research

Agency type	Number of agencies that have projects that are potentially suitable for evaluation as part of this research				
	Yes		No		Total
State agencies	4	(19.0)	17	(81.0)	21
Local agencies	9	(50.0)	9	(50.0)	18
Total	13	(33.3)	26	(66.7)	39

TABLE B-32 Number of agencies that implemented projects that resulted in an increase in U-turn volumes due to closing of existing unsignalized median openings

Agency type	Number (percentage) of agencies that have recently implemented projects in which an existing unsignalized median opening was closed resulting in increased U-turn volumes at adjacent median openings				
	Yes		No		Total
State agencies	13	(56.7)	17	(43.3)	30
Local agencies	7	(29.2)	17	(70.8)	24
Total	20	(37.0)	34	(63.0)	54

TABLE B-33 Number of agencies and estimated number of projects that closed existing unsignalized median openings

Agency type	Number of agencies that have such projects	Total number of projects	Average number of projects
State agencies	7	78	11
Local agencies	4	12	3
Total	11	90	8

TABLE B-34 Number of agencies that experienced safety or operational problems related to the closing of existing unsignalized median openings

Agency type	Number (percentage) of agencies that have safety or operational problems related to U-turn maneuvers in conjunction with projects in which unsignalized median openings were closed				
	Yes		No		Total
State agencies	1	(6.7)	14	(93.3)	15
Local agencies	0	(0.0)	16	(100.0)	16
Total	1	(3.2)	30	(96.8)	31

did not specify the nature of the problem other than to say that it involved an increase in U-turns at other locations.

The responding state and local agencies were also asked if they have performed any formal before-after evaluations of projects in which an unsignalized median opening was closed. Table B-35 summarizes the responses to this question. Three agencies indicated that they performed such evaluations. Table B-36 summarizes the number of state and local agencies that have projects involving closure of unsignalized median openings that may be suitable for evaluation as part of this research. Nine agencies (five state and four local agencies) indicated that they may have such projects.

TABLE B-35 Number of agencies that have performed formal before-after evaluations of projects involving closure of an existing unsignalized median opening

Agency type	Number (percentage) of agencies that have performed formal before-after evaluations of projects involving closure of existing unsignalized median openings				
	Yes		No		Total
State agencies	2	(7.4)	25	(92.6)	27
Local agencies	1	(5.9)	16	(94.1)	17
Total	3	(6.8)	41	(93.2)	44

TABLE B-36 Number of agencies that may have projects involving closure of existing unsignalized median openings that may be suitable for evaluation as part of this research

Agency type	Number (percentage) of agencies that may have suitable projects involving closure of existing unsignalized median openings for evaluation as part of this research				
	Yes		No		Total
State agencies	5	(23.8)	14	(76.2)	19
Local agencies	4	(30.8)	9	(69.2)	13
Total	9	(28.1)	23	(71.9)	32

APPENDIX C

GUIDELINES FOR THE USE, LOCATION, AND DESIGN OF UNSIGNALIZED MEDIAN OPENINGS

This appendix presents guidelines for the use, location, and design of unsignalized median openings. The guidelines include a classification and assessment of typical median opening designs, a discussion of the factors that influence the safety and operational performance of median openings, and a methodology that can be used to compare the expected safety performance of two or more median opening design alternatives.

MEDIAN TREATMENTS

The selection of median treatment has important bearing on how well a roadway will operate, its safety performance, and the access provided to adjacent developments. The basic options for median treatment include:

- No median (undivided roadway)
- Continuous two-way left-turn lane (TWLTL)
- Nontraversable median

NCHRP Report 395, *Capacity and Operational Effects of Mid-Block Left-Turn Lanes* (*15*), compares the relative traffic operational and safety performance of these three median options. Table C-1 presents a comparison of these three median options, indicating which option is preferred with respect to operational, safety, access, and other factors.

Many studies have analyzed the safety benefits of installing TWLTLs or nontraversable medians on undivided highways, and replacing TWLTLs with nontraversable medians. NCHRP Report 420, *Impacts of Access Management Techniques* (*4*), presents a summary of the individual studies and compares their results for each of the three median options. Figures C-1 and C-2 present accident rates by median type and total access density (both directions) for urban-suburban and rural roadways, respectively. Roadways with nontraversable medians consistently have a lower accident rate than undivided roadways or roadways with TWLTLs.

The preceding tables and figures show the reasons why highway agencies are increasingly using nontraversable medians on arterial highways. Provision of a nontraversable median is likely to result in increased U-turn demand. However, it is unlikely that the increased U-turn demand can be met solely at signalized intersections. Therefore, unsignalized median openings are likely needed to accommodate both U-turn demand and left-turn access, where appropriate. The following discussion addresses various types of unsignalized median openings and guidelines for their use and design.

CLASSIFICATION AND ASSESSMENT OF TYPICAL MEDIAN OPENING DESIGNS

A classification system is presented to identify how particular median openings function and where they are located relative to other elements of the highway system. This section presents the factors used in the classification process and provides an overview of typical median designs.

Factors Used in Classification of Median Opening Designs

The four key factors used to classify or describe the design of a median opening are:

- Type of geometry
- Degree of access served
- Presence of left-turn lanes
- Presence of loons

The first factor, type of geometry, determines which movements are possible at a median opening. Conventional median openings (sometimes referred to as "full median openings") typically permit all movements, while directional median openings may restrict certain movements. Jughandles are an indirect left-turn treatment that enable drivers to make U-turn and left-turn maneuvers efficiently on divided highways with relatively narrow medians.

The second factor, degree of access served, not only determines what movements need to be accommodated at a median opening, but also the number of potential conflict points a median opening will have. For example, a median opening that only serves U-turn maneuvers will have considerably fewer conflicting maneuvers than a median opening at a three- or four-leg intersection, where U-turns use the same roadway as left-turn and crossing maneuvers. Median openings can be classified by whether access points are present on neither side, one side, or both sides of the roadway. Access points at median openings may include either intersecting public roads or driveways.

The third factor used in the classification is whether or not a median opening has a left-turn lane. Median openings generally operate better when left-turn lanes are present to provide a deceleration and storage area for vehicles before they enter the median. In fact, the AASHTO *Green Book* specifically encourages the use of left-turn lanes at median openings to reduce or eliminate stopping on the through lanes (*3*).

TABLE C-1 Comparison of effects of three alternative cross-sections with differing midblock left-turn treatment types (*15*)

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

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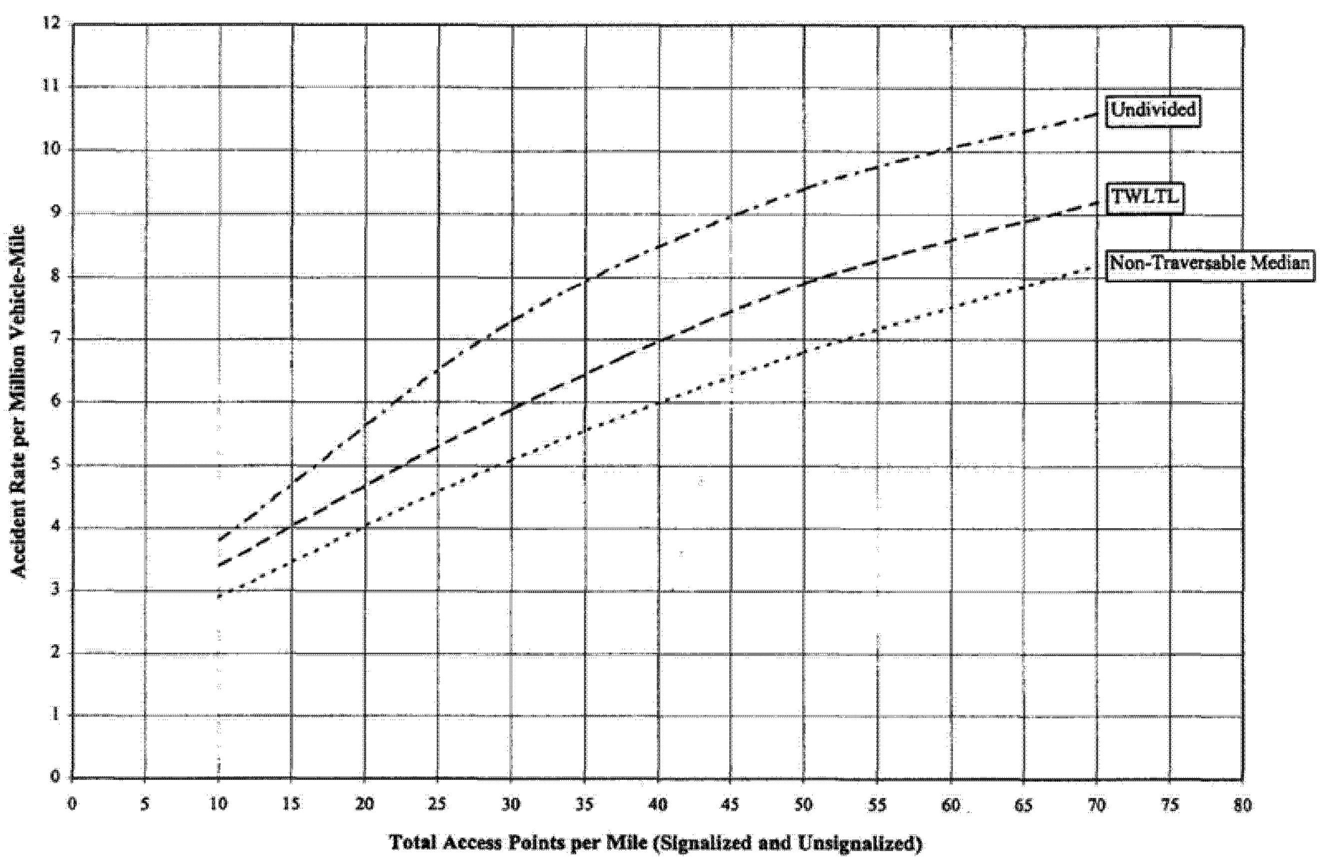


Figure C-1. Estimated accident rates by type of median-urban and suburban areas.

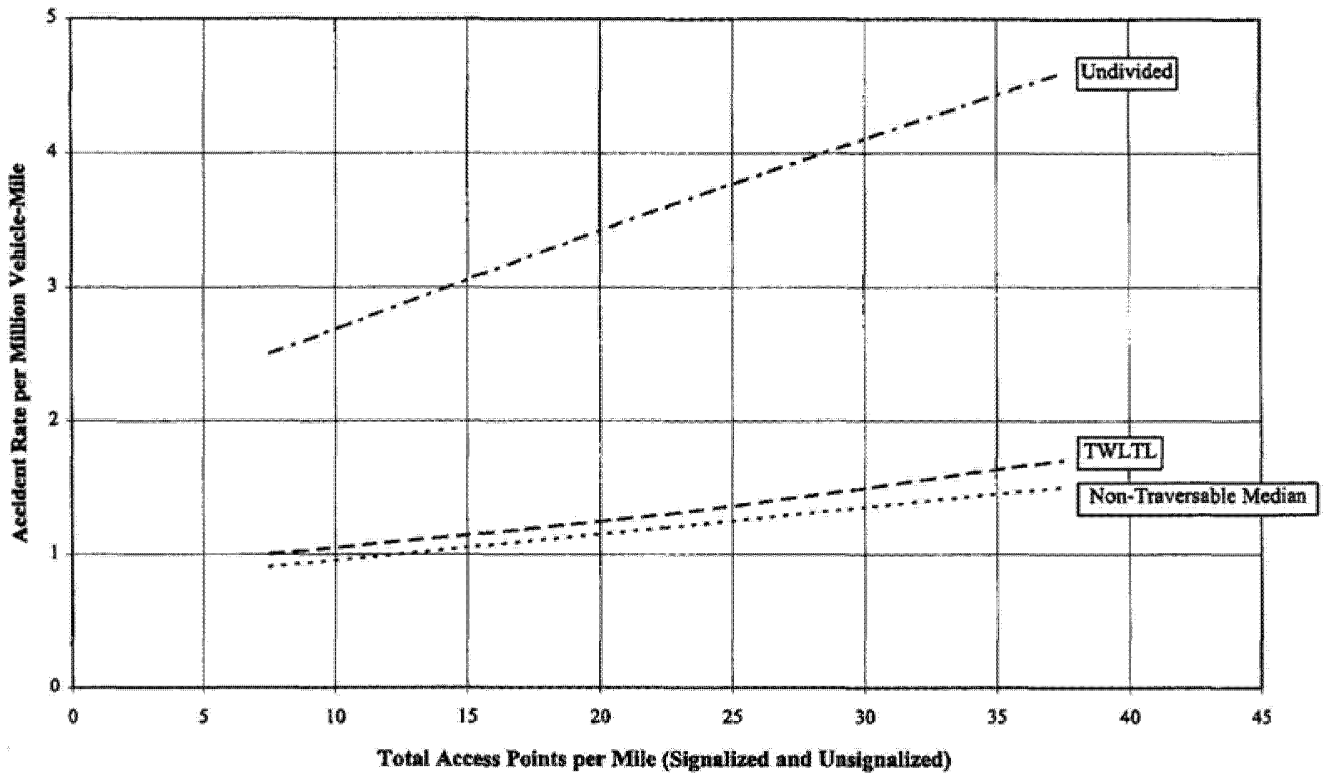


Figure C-2. Estimated accident rates by type of median-rural areas (4).

The final factor in classification of median openings is whether or not a median opening is accompanied by a loon. A loon is an expanded paved apron on the shoulder opposite a median crossover. The purpose of loons is to provide additional space for larger vehicles (particularly trucks) to negotiate turns, and thus, to allow the installation of conventional or directional median openings along narrow medians. The provision of loons to serve U-turns by large vehicles is a new technique that formalizes past use of paved shoulders for the same purpose. Initial results by highway agencies that have used loons appear promising (*55, 56*).

Based on the four factors discussed above, median openings can be classified based on their design characteristics as follows:

- Type of geometry (traffic movements permitted)
  - conventional (all movements permitted)
  - directional
- Degree of access served
  - U-turn only (midblock median opening)
  - access on one side (at three-leg intersection)
  - access on two sides (at four-leg intersection)
- Presence of left-turn lane
  - no left-turn lane present
  - left-turn lane present
- Presence of loon
  - no loon present
  - loon present

Overview of Typical Median Opening Designs

Using the first two classification factors (geometry type and degree of access served), typical median openings can be classified into the following six categories:

1. Conventional Midblock Median Opening
2. Directional Midblock Median Opening
3. Conventional Median Opening at Three-Leg Intersection
4. Directional Median Opening at Three-Leg Intersection
5. Conventional Median Opening at Four-Leg Intersection
6. Directional Median Opening at Four-Leg Intersection

These six categories of median openings can be subdivided based on the presence of left-turn lanes or loons and the types of turning maneuvers permitted. With these subdivisions, there are a total of fifteen typical median opening designs. The following discussion presents each of the six categories of median openings and the specific designs used for those openings. The discussion of each median opening design includes a figure with a diagram of each median opening design and a list of the advantages and disadvantages associated with each design.

Conventional Midblock Median Opening

A conventional midblock median opening permits vehicles to make U-turns, but does not provide separate channelized roadways for vehicles making U-turns in opposing directions. Median openings at midblock locations are appropriate on arterials where providing for U-turn maneuvers between intersections may improve operations at intersections by reducing the U-turn volumes at those intersections or reducing the amount of out-of-direction travel for vehicles trying to reach a destination without direct left-turn access. Conventional median openings are appropriate where U-turn volumes are relatively low, such that U-turn vehicles in opposing directions of travel create minimal interference with one another.

The conventional midblock median opening design is further classified into three subcategories based on the presence of left-turn lanes and/or loons:

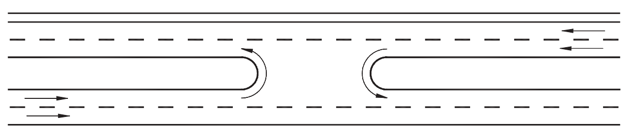
Type 1a—Conventional Midblock Median Opening Without Left-Turn Lanes
Type 1b—Conventional Midblock Median Opening With Left-Turn Lanes
Type 1c—Conventional Midblock Median Opening With Left-Turn Lanes and Loons

Figures C-3 through C-5 illustrate these three median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Types 1b and 1c reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles. The presence of loons in Type 1c provides a widening in the pavement to accommodate U-turn movements by larger vehicles, such as emergency vehicles and trucks.

Directional Midblock Median Opening

A directional midblock median opening permits vehicles to make U-turns and provides separate channelized roadways for vehicles making U-turns in opposite directions. Thus, opposing U-turn vehicles will not overlap. Median openings at mid-

Type 1a—Conventional Midblock Median Opening Without Left-Turn Lanes



Advantages

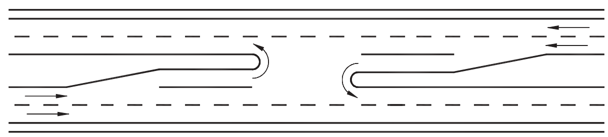
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.

Figure C-3. Advantages and disadvantages of median opening type 1a—conventional midblock median opening without left-turn lanes.

Type 1b—Conventional Midblock Median Opening With Left-Turn Lanes



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.

Figure C-4. Advantages and disadvantages of median opening type 1b—conventional midblock median opening with left-turn lanes.

block locations are appropriate on arterials where providing for U-turn maneuvers between intersections may improve operations at intersections by reducing the U-turn volumes at those intersections or reducing the amount of out-of-direction travel for vehicles trying to reach a destination without direct left-turn access. Directional median openings are appropriate where U-turn volumes are relatively high, such that U-turn vehicles in opposing directions of travel would otherwise interfere with one another.

The directional midblock median opening design is further classified into three subcategories based on the presence of left-turn lanes and/or loons:

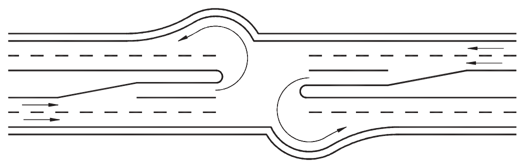
Type 2a—Directional Midblock Median Opening Without Left-Turn Lanes
Type 2b—Directional Midblock Median Opening With Left-Turn Lanes
Type 2c—Directional Midblock Median Opening With Left-Turn Lanes and Loons

Figures C-6 through C-8 illustrate these three median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Types 2b and 2c reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles. The presence of loons in Type 2c provides a widening in the pavement to accommodate U-turn movements by larger vehicles, such as emergency vehicles and trucks.

Conventional Median Opening at Three-Leg Intersection

A conventional median opening at a three-leg intersection permits vehicles on the major road to make U-turn movements on the major road and left- or right-turning movements

Type 1c—Conventional Midblock Median Opening With Left-Turn Lanes and Loons



Advantages

- Widening on the far side of the turn makes it possible to make a U-turn without stopping or backing and reduces interference between U-turn and through traffic, particularly for large vehicles.
- Without performing major reconstruction, additional space can be provided to facilitate the larger turning path of commercial vehicles along narrow medians.
- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- With no directional island, opposing U-turn vehicles may have to overlap.
- The presence of loons may make snow removal and other maintenance work more difficult.

Figure C-5. Advantages and disadvantages of median opening type 1c—conventional midblock median opening with left-turn lanes and loons.

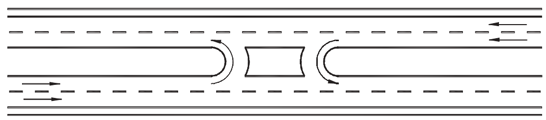
onto the minor road. Vehicles on the minor road may make left or right turns onto the major road. No separate channelized roadways are provided for vehicles making U-turns in opposing directions. Thus, U-turn vehicles may overlap with opposing U-turn or left-turn vehicles. Median openings at three-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects. Conventional median openings are appropriate where it is desirable to allow left-turning movements from both the major road and the minor road (or driveway) and where U-turn volumes are relatively low, such that U-turn vehicles in opposing directions of travel create minimal interference with one another.

The conventional median opening design at a three-leg intersection is further classified into four subcategories based on the presence of a left-turn lane and/or loon:

Type 3a—Conventional Median Opening Without Left-Turn Lanes at Three-Leg Intersection
Type 3b—Conventional Median Opening With One Left-Turn Lane at Three-Leg Intersection
Type 3c—Conventional Median Opening With Two Left-Turn Lanes at Three-Leg Intersection
Type 3d—Conventional Median Opening With Left-Turn Lanes and Loons at Three-Leg Intersection

Figures C-9 through C-12 illustrate these four median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Types 3b, 3c, and 3d reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles. The presence of loons in Type 3d provides a widening in the pavement to accommodate U-turn movements by larger vehicles, such as emergency vehicles and trucks.

Type 2a—Directional Midblock Median Opening Without Left-Turn Lanes



Advantages

- This design prevents overlapping U-turns.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.

Figure C-6. Advantages and disadvantages of median opening type 2a—directional midblock median opening without left-turn lanes.

Directional Median Opening at Three-Leg Intersection

There are two types of directional median openings at three-leg intersections:

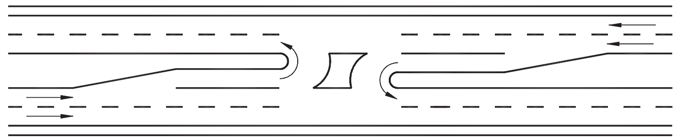
Type 4a—Directional Median Opening for Left Turns from Major Road at Three-Leg Intersection
Type 4b—Direction Median Opening for Left Turns onto Major Road at Three-Leg Intersection

The first type, designated as Type 4a, permits vehicles to turn left off the major road onto the minor road and to make U-turn maneuvers on the major road, but does not permit vehicles to turn left from the minor road onto the major road. The second type, designated as Type 4b, permits vehicles to turn left or right from the minor road onto the major road and vehicles on the major road to make U-turn maneuvers, but does not permit vehicles to turn left off the major road onto the minor road. Median openings at three-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects.

Directional median openings are appropriate where U-turn or left-turn volumes are relatively high, such that a conventional median opening would experience considerable interference between vehicles entering the median opening. Directional median openings are also appropriate where there is a disproportionately high left-turn demand from either the major road or the minor road and, therefore, either Type 4a or Type 4b would accommodate the needs of the intersection. Directional median openings are desirable where an intersection is going to be signalized, since it only impacts major-road traffic in one direction and effective two-direction signal coordination can be maintained (*5*).

Figures C-13 through C-14 illustrate these two median opening designs and their advantages and disadvantages.

Type 2b—Directional Midblock Median Opening With Left-Turn Lanes



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- This design prevents overlapping U-turns.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only four conflict points, which is less than at a three-leg or four-leg intersection.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.

Figure C-7. Advantages and disadvantages of median opening type 2b—directional midblock median opening with left-turn lanes.

Conventional Median Opening at Four-Leg Intersection

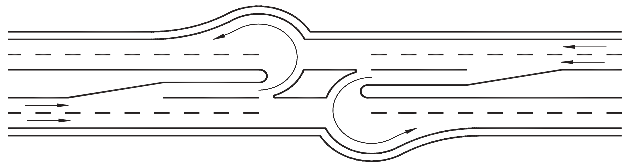
A conventional median opening at a four-leg intersection permits vehicles on the major road to make U-turn movements on the major road and left- or right-turning movements onto the minor road. Vehicles on the minor road may make left or right turns onto the major road. No separate channelized roadways are provided for vehicles making U-turns in opposing directions. Thus, U-turn vehicles may overlap with opposing U-turn or left-turn vehicles. Median openings at four-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects. Conventional median openings are appropriate where it is desirable to allow left-turning movements from both the major road and the minor road (or driveway) and where U-turn volumes are relatively low, such that U-turn vehicles in opposing directions of travel create minimal interference with one another.

The conventional median opening design at a four-leg intersection is further classified into two subcategories based on the presence of left-turn lanes:

Type 5a—Conventional Median Opening Without Left-Turn Lanes at Four-Leg Intersection
Type 5b—Conventional Median Opening With Left-Turn Lanes at Four-Leg Intersection

Figures C-15 and C-16 illustrate these two median opening designs and their advantages and disadvantages. The presence of left-turn lanes in Type 5b reduces the potential for rear-end collisions between U-turn vehicles and following through vehicles.

Type 2c—Directional Midblock Median Opening With
Left-Turn Lanes and Loons



Advantages

- Widening on the far side of the turn makes it possible to make a U-turn without stopping or backing and reduces interference between U-turn and through traffic, particularly for large vehicles.
- Without performing major reconstruction, additional space can be provided to facilitate the larger turning path of commercial vehicles along narrow medians.
- The presence of left-turn lanes reduces potential for rear-end collisions between U-turn vehicles and following through vehicles.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- This design prevents overlapping U-turns.
- Midblock access is provided for vehicles to (a) make a U-turn and (b) reach driveways on the opposite side of the street.
- Since only major-road traffic is involved, delays to vehicles making U-turns will be less than where an intersection is present.
- If U-turn traffic would otherwise proceed downstream to an intersection with a median opening, then this treatment should reduce VMT.
- Providing median openings for U-turns between intersections reduces the number of turning maneuvers at the intersections.
- Accident rates at midblock median openings are lower than at three- or four-leg median openings.

Disadvantages

- The presence of loons may make snow removal and other maintenance work more difficult.

Figure C-8. Advantages and disadvantages of median opening Type 2c—directional midblock median opening with left-turn lanes and loons.

Directional Median Opening for Left Turns from Major Road at Four-Leg Intersection

A directional median opening at a four-leg intersection permits vehicles to turn left off the major road onto the minor road and to make U-turn maneuvers on the major road, but does not permit vehicles to turn left from the minor road onto the major road. Median openings at four-leg intersections are appropriate along arterial roadways at street intersections or driveways to major developments where providing access across the median will not create undesirable safety or traffic operational effects. Directional median openings are appropriate where U-turn or left-turn volumes are relatively high, such that a conventional median opening would experience considerable interference between vehicles entering the median opening. This particular directional median opening design is also appropriate where there is a disproportionately high left-turn demand from the major road. Directional median openings are desirable where an intersection is going to be signalized, since it only impacts major-road traffic in one direction and effective two-direction signal coordination can be maintained (*NCHRP Report 348*). This median opening design is represented in the classification as:

Type 6a—Directional Median Opening for Left Turns from Major Road at Four-Leg Intersection

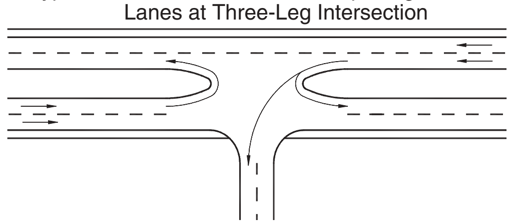
Figure C-17 illustrates this median opening design and its advantages and disadvantages.

LOCATION AND DESIGN GUIDELINES

This section presents guidelines on the location and design of median openings based on the following factors:

- Major- and minor-road volumes
- Left-turn and U-turn volumes
- Median width
- Median opening length

Type 3a—Conventional Median Opening Without Left-Turn Lanes at Three-Leg Intersection



Advantages

- Vehicles on the minor road can make both left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 11 conflict points, which is less than at a four-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where six-lane or eight-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.

Figure C-9. Advantages and disadvantages of median opening type 3a—conventional median opening without left-turn lanes at three-leg intersection.

- Minimum spacing between median openings
- Sight distance
- Loons to assist vehicles in completing U-turn maneuvers
- Median opening types

Major- and Minor-Road Volumes

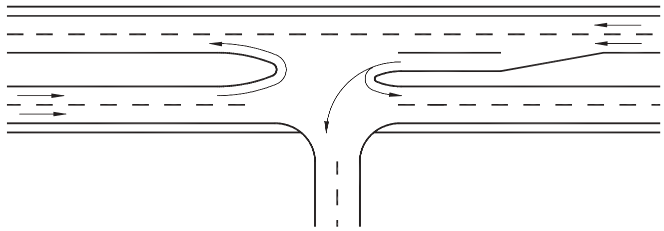
Unsignalized median openings may be used for a broad range of major- and minor-road traffic volumes. However, if the major- and minor-road volumes exceed the traffic volumes given in the MUTCD signalization warrants, signalization of the median opening should be considered.

No safety prediction models relating median opening accident frequencies to major- and minor-road volumes are available. Safety prediction models for divided highway intersections that consider major- and minor-road traffic volumes are currently being developed for use in the *Highway Safety Manual*. Once appropriate safety prediction models are developed, they should be used in comparing alternative median opening designs. While the full major- and minor-road traffic volumes cannot currently be considered in the location and design of median openings, consideration can be given to median opening volumes (U-turns and left turns), as discussed in the next section.

U-turn and Left-Turn Volumes

Field studies at a variety of median opening types in urban arterial corridors have found estimated U-turn volumes rang-

Type 3b—Conventional Median Opening With One Left-Turn Lane at Three-Leg Intersection



Advantages

- The presence of a left-turn lane in one direction of travel reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for one direction of travel only on the major road.
- The presence of a left-turn lane in the direction of travel mitigates the problem of U-turn vehicles in that direction encroaching on the adjacent lane and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can make left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 11 conflict points, which is less than at a four-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

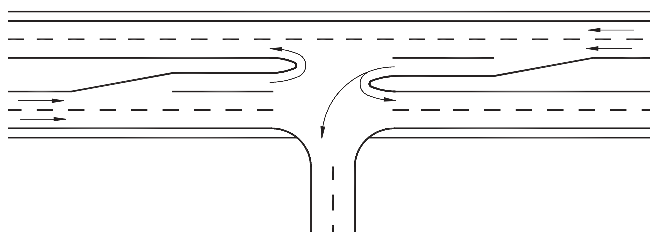
Disadvantages

- U-turn vehicles in the direction of travel without a left-turn lane forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- Vehicles on the major road in the direction of travel without a left-turn lane must initiate U-turn maneuvers from the through lane, which may delay through vehicles and create the potential for rear-end collisions.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-second gaps are needed to cross traffic, possibly even 10 sec where six-lane or eight-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.

Figure C-10. Advantages and disadvantages of median opening type 3b—conventional median opening with one left-turn lane at three-leg intersection.

ing from 2 to 977 veh/day, representing from 0.01 to 3.2 percent of the major-road traffic volumes at those locations. At median openings in rural areas, U-turn volumes were found to range from 88 to 374 veh/day, representing 0.41 to 1.36 percent of the major-road traffic volumes at those locations. The available data are not sufficient to develop satisfactory regression relationships to relate median opening accident frequency to median opening volumes. It is also not possible to separately account for the effects of U-turn and left-turn volumes on safety at median openings. However, Table C-2 presents the accident rates per median opening traffic movement for various area and median opening types. The median opening traffic volume is the sum of the U-turn and left-turn volumes through the median opening. Computational proce-

Type 3c—Conventional Median Opening With Two Left-Turn Lanes at Three-Leg Intersection



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can make both left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 11 conflict points, which is less than at a four-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.

Figure C-11. Advantages and disadvantages of median opening type 3c—conventional median opening with two left-turn lanes at three-leg intersection.

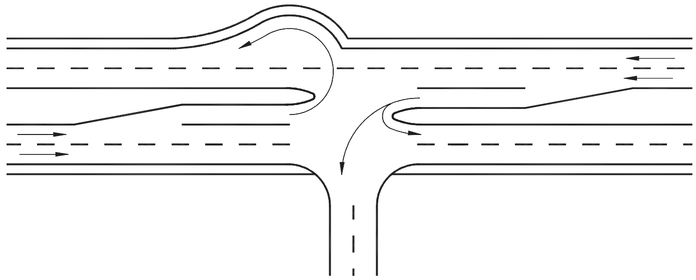
dures for using the average accident rates in Table C-2 in comparing alternative median opening arrangements are presented later in these guidelines.

The reason that the effects of U-turn and left-turn volumes on median opening accident frequency cannot be separated is that review of accident data for median openings have found that accident report data do not distinguish clearly between accidents involving U-turn maneuvers and those involving left-turn maneuvers. In particular, at some median openings where U-turn maneuvers can be made but no left-turn maneuvers are feasible, investigating officers classified a substantial proportion of the accidents involving turning movements through the median as related to left-turn maneuvers.

Left-Turn Lanes

Vehicles turning left from a multilane highway may pose safety and operational problems at median openings. They not only increase conflicts with and delays to other vehicles, but also pose a major safety problem with the large speed differential between left-turning and through vehicles.

Type 3d—Conventional Median Opening With Left-Turn Lanes and Loons at Three-Leg Intersection



Advantages

- Widening on the far side of the turn makes it possible to make a U-turn without stopping or backing and reduces interference between U-turn and through traffic, particularly for large vehicles.
- Without performing major reconstruction, additional space can be provided to facilitate the larger turning path of commercial vehicles along narrow medians.
- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can make left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the cross street and make U-turns on the major road.
- Delays will be less than at a four-leg intersection.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

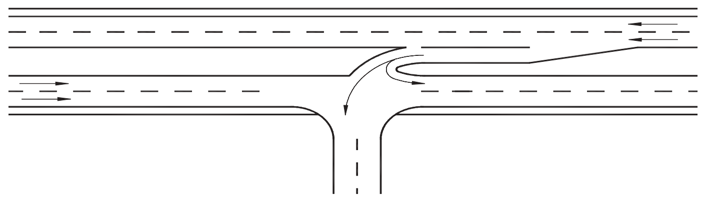
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Narrow medians may not provide enough space for larger vehicles to negotiate a U-turn.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the minor road may experience long delays.
- The presence of a loon may make snow removal and other maintenance work more difficult.

Figure C-12. Advantages and disadvantages of median opening type 3d—conventional median opening with left-turn lanes and loons at three-leg intersection.

In a recent FHWA study, a before-after evaluation of the safety effects of providing left-turn lanes for at-grade intersections was conducted. The research concluded that providing left-turn lanes is effective in improving safety at unsignalized intersections in both rural and urban areas. Specifically, at urban unsignalized intersections, the research found that installation of a left-turn lane on one approach would be expected to reduce accidents by 27 percent for four-leg intersections and by 33 percent for three-leg intersections.

Left-turn lanes are often installed at median openings to accommodate high left-turning volumes. Harmelink (*67*) provides volume warrants and design charts for left-turn lanes at

Type 4a—Directional Median Opening for Left Turns From Major Road at Three-Leg Intersection



Advantages

- The presence of a left-turn lane reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles on the major road.
- The presence of a left-turn lane mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the major road have direct left-turn access to the minor road.
- Vehicles on the major road can make U-turn maneuvers in one direction of travel.
- Right-turn maneuvers are unaffected by this treatment.
- For those maneuvers permitted, delays will be less than at a conventional median opening at a three-leg intersection.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only six conflict points, which is less than at a conventional median opening at a three-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- Minor road vehicles do not have direct left-turn access to the major road.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Additional VMT will be incurred by vehicles whose drivers desire to turn left from the minor road onto the major road.

Figure C-13. Advantages and disadvantages of median opening type 4a—directional median opening for left turns from major road at three-leg intersection.

unsignalized intersections on four-lane highways. Many highway agencies, however, have adopted a policy of providing left-turn lanes at virtually all median openings at divided highways.

Median Width

The safety and operational effects of median width at signalized and unsignalized intersections on divided highways were evaluated extensively in NCHRP Report 375, *Median Intersection Design* (*8*), and the design policy recommendations of that report have been incorporated in the AASHTO *Green Book* (*3*). Guidelines for selecting median widths at unsignalized intersections on divided highways, as recommended in NCHRP Report 375 and the *Green Book*, are presented below.

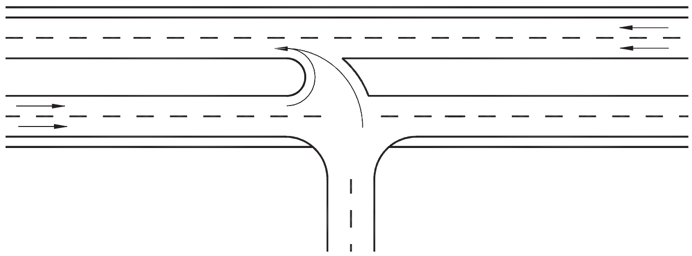
Rural Unsignalized Intersections

- Rural unsignalized intersections should have medians that are as wide as practical, as long as the median is not so wide that approaching vehicles on the crossroad cannot see both roadways of the divided highway.
- Where the AASHTO passenger car is used as the design vehicle, a minimum median width of 8 m (25 ft) is recommended.
- Where a large truck is used as the design vehicle, a median width of 21 to 31 m (70 to 100 ft) generally should be selected.

Suburban Unsignalized Intersections

- Median widths at suburban unsignalized intersections generally should be as narrow as possible while provid-

Type 4b—Directional Median Opening for Left Turns Onto Major Road at Three-Leg Intersection



Advantages

- Vehicles on the minor road have direct left-turn access to the major road.
- Vehicles on the major road in one direction of travel can make U-turn maneuvers.
- Right-turn maneuvers are unaffected by this treatment.
- Delays will be less than at a conventional median opening at a three-leg intersection.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only six conflict points, which is less than at a conventional median opening at a three-leg intersection.
- Accident rates at three-leg intersections are lower than at four-leg intersections.

Disadvantages

- Vehicles on the major road do not have direct left-turn access to the cross street.
- The absence of a left-turn lane on the major road increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Additional VMT will be incurred by vehicles whose drivers desire to turn left from the major road onto the minor road.

Figure C-14. Advantages and disadvantages of median opening type 4b—directional median opening for left turns onto major road at three-leg intersection.

ing sufficient space in the median for the appropriate left-turn treatment.

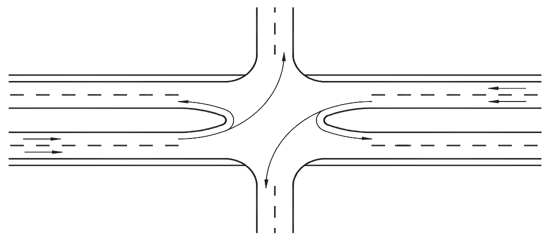
- Median widths between 4.2 and 7.2 (14 and 24 ft) will accommodate left-turn lanes, but are not wide enough to store a crossing or turning vehicle in the median.
- Medians wider than 7.6 m (25 ft) may be used, but cross-road vehicles making turning and crossing maneuvers may stop on the median roadway.
- Median widths of more than 15 m (50 ft) generally should be avoided at suburban, unsignalized intersections.

The design vehicle for choosing the median width at a divided highway intersection is generally based on the vehicle mix for vehicles making turning and crossing maneuvers. However, at unsignalized median openings with substantial U-turn volumes, the vehicle mix for U-turn maneuvers should be a major consideration in selecting the design vehicle for determining median opening width. Figure C-18 illustrates the AASHTO *Green Book* criteria for determining the median and roadway widths needed to provide for U-turns at unsignalized median openings. Where the full median width and roadway width needed to accommodate U-turn maneuvers cannot be provided, consideration should be given to inclusion of a loon in the design (see below).

Median Opening Length

NCHRP Report 375 (*8*) states that median opening lengths at rural divided highway intersections generally should be kept to the minimum possible. Increases in median opening length were found to be correlated with higher rates of undesirable driving behavior. By contrast, at median openings in urban and suburban areas, the median width should not be

Type 5a—Conventional Median Opening Without Left-Turn Lanes at Four-Leg Intersection



Advantages

- Vehicles on the minor road can either cross the major road or make left and right turns onto the major road.
- Vehicles on the major road in both directions of travel can make left and right turns onto the minor road and make U-turns on the major road.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.

Disadvantages

- The absence of left-turn lanes increases potential for rear-end collisions between U-turn vehicles and following through vehicles.
- U-turn vehicles forced to stop in the median opening may encroach on adjacent lanes and interfere with through traffic.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the cross street may experience long delays.
- There are 32 potential conflict points with both minor-road and major-road vehicles entering the median opening.
- Accident rates at four-leg intersections are higher than at three-leg intersections.

Figure C-15. Advantages and disadvantages of median opening type 5a—conventional median opening without left-turn lanes at four-leg intersection.

greater than necessary (as noted above), but there does not appear to be any reason that the median opening should not be as long as necessary.

Minimum Spacing Between Median Openings

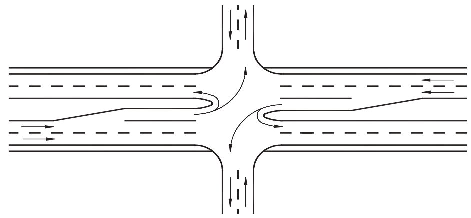
Guidelines for the minimum spacing between median openings are based on recommendations of NCHRP Report 420 (*4*) and the results of the highway agency survey conducted as part of this research. They are:

- Median opening spacing for rural areas typically ranges from 150 to 805 m (500 to 2,640 ft); a minimum median opening spacing of 150 m (500 ft) is recommended in rural areas. Typically, median opening spacing substantially longer than 150 m (500 ft) is appropriate, unless two public road intersections or major driveways are located relatively close together.
- Median opening spacing for urban areas typically ranges from 90 to 805 m (300 to 2,640 ft); a minimum median opening spacing of 90 m (300 ft) is recommended in urban areas. Whenever practical, median opening spacing greater than 90 m (300 ft) should be used in urban areas.

Sight Distance

Intersection sight distance (ISD) is an important design and operational consideration at all intersections, but is especially important at divided highway intersections, including unsignalized median openings, where the presence of the median may increase the ISD needs or provide a location for potential sight obstructions that reduce the ISD. U-turn maneu-

Type 5b—Conventional Median Opening With Left-Turn Lanes at Four-Leg Intersection



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the minor road can either cross the major road or make left and right turns onto the major road.
- Vehicles on the major road can make left and right turns onto the minor road and make U-turns on the major road.
- No additional VMT is incurred by vehicles making left-, right-, or U-turning maneuvers.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.

Disadvantages

- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- With no directional island, opposing U-turn vehicles may have to overlap.
- Minimum 6- to 8-sec gaps are needed to cross traffic, possibly even 10 sec where 6-lane or 8-lane arterials must be crossed. These gaps will be limited during busy travel period on heavily used arterials.
- Where peak-hour traffic exceeds critical volumes, vehicles entering the major road from the cross street may experience long delays.
- There are 32 potential conflict points with both cross-street and major-road vehicles entering the median opening.
- Accident rates at four-leg intersections are higher than at three-leg intersections.

Figure C-16. Advantages and disadvantages of median opening type 5b—conventional median opening with left-turn lanes at four-leg intersection.

vers should not be encouraged at locations with limited sight distance. Furthermore, sight distance is an important issue in determining locations where U-turns by larger vehicles should be permitted/encouraged.

NCHRP Report 383 (*57*) presents revised ISD models that have been adopted by AASHTO and incorporated into the 2001 *Green Book* (*3*). The following ISD cases are applicable to unsignalized median openings:

- Case B1 (left turns from the minor road)
- Case B3 (crossing maneuvers)
- Case F (left turns from the major road)

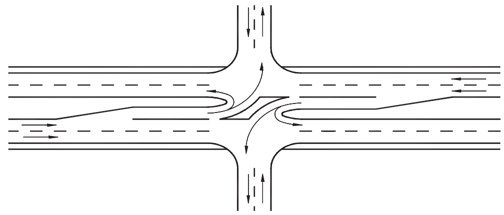
Each ISD case is described in more detail below.

Left Turns from the Minor Road (Case B1)

Case B1 involves a situation in which a vehicle is stopped on the minor road awaiting an opportunity to complete a left-turn maneuver by clearing traffic approaching from the left and then enters the traffic stream approaching from the right. *Green Book* Exhibit 9-55 presents design ISD criteria for Case B1.

At divided-highway intersections, sight distance design for left turns may need to consider multiple design vehicles. If the design vehicle used to determine sight distance for a divided-highway intersection is larger than a passenger car, then sight distance for left turns will need to be checked for that selected design vehicle. The *Green Book* includes guid-

Type 6a—Directional Median Opening for Left Turns From Major Road at Four-Leg Intersection



Advantages

- The presence of left-turn lanes reduces potential for rear-end collisions between left-turn or U-turn vehicles and following through vehicles for both directions of travel on the major road.
- The presence of left-turn lanes mitigates the problem of U-turn vehicles encroaching on adjacent lanes and interfering with through traffic while waiting for a gap in the opposing traffic.
- Vehicles on the major road have direct left-turn access to the minor road.
- Vehicles on the major road in both directions of travel can make U-turn maneuvers.
- Right-turn maneuvers are unaffected by this treatment.
- Delays will be less than at a conventional median opening at a four-leg intersection.
- Since vehicles making a U-turn only need to enter, but not cross, the opposing roadway, a minimum gap of only 4 to 6 sec will be needed.
- There are only 12 conflict points, which is less than at a conventional median opening at a four-leg intersection.
- Accident rates at directional four-leg median openings are lower than at conventional four-leg median openings.

Disadvantages

- Minor-road vehicles do not have direct left-turn access to the major road.
- U-turn vehicles entering the through lanes may delay full-speed through traffic.
- Accident rates at four-leg intersections are higher than at three-leg intersections.
- No direct crossing maneuver on minor road.
- Additional VMT will be incurred by vehicles whose drivers desire to make crossing maneuvers on the minor road and left-turn maneuvers from the minor road to the major road.

Figure C-17. Advantages and disadvantages of median opening type 6a—directional median opening for left turns from major road at four-leg intersection.

ance for median widths large enough to store the design vehicle and for median widths not large enough to store the design vehicle.

Crossing Maneuvers (Case B3)

Case B3 involves a situation in which a vehicle is stopped on the minor road awaiting an opportunity to cross the major road by clearing traffic approaching from the left and from the right. *Green Book* Exhibit 9-58 presents design ISD criteria for Case B3. In most cases, the sight distance provided in Case B1 will provide more than adequate sight distance for minor-road vehicles to cross the major road. However, in the following situations, it is advisable to check the availability of sight distance for crossing maneuvers:

- where left and/or right turns are not permitted from a particular approach and the crossing maneuver is the only legal maneuver;
- where the crossing vehicle would cross the equivalent width of more than six lanes; or
- where substantial volumes of heavy vehicles cross the highway and steep grades that might slow the vehicles while its back portion is still in the intersection are present on the departure roadway on the far side of the intersection.

Left Turns from the Major Road (Case F)

Case F involves a situation in which a vehicle is stopped on the major road awaiting an opportunity to complete a left-

TABLE C-2 Median opening accident rate by median opening type

Median opening type	Number of median openings	Total median opening accident frequency[a] (for entire study period)	Median opening movements (10^6 turns during entire study period)	Median opening accident rate (accidents per 10^6 turning vehicles)
URBAN ARTERIAL CORRIDORS				
Midblock				
1a	7	1	–[b]	–[b]
2b	20	4	17.20	0.23
2c	10	5	13.42	0.37
Three-leg				
3a	11	9	2.23	4.04
3b	19	32	13.04	2.46
3c	2	10	1.20	8.35
4a	4	7	4.87	1.44
Four-leg				
5a	8	26	11.16	2.33
5b	17	76	22.77	3.34
6a	5	42	16.36	2.57
RURAL ARTERIAL CORRIDORS				
Midblock				
1a	7	3	0.96	3.13
Three-leg				
3a	4	4	4.65	0.86
Four-leg				
5a	1	4	1.41	2.84

[a] The duration of the study period was generally five years. However, only four years of accident and exposure data were available for sites in New Jersey, and six years of accident and exposure data were available for sites in New York.
[b] Data too limited to be meaningful.

turn maneuver by waiting for an appropriate gap in opposing traffic to complete their turn. *Green Book* Exhibit 9-67 presents design ISD criteria for Case F.

On divided highways, while the geometry of the roadway may provide sufficient sight distance for left turns from the major road, some intersections may experience additional sight-distance concerns, such as: (1) sight obstructions in the median or (2) opposing left-turn vehicles obstructing the view of a left-turning vehicle. The sight restrictions created by opposing left-turn vehicles on divided highways can be minimized by the use of parallel and tapered offset left-turn lanes, as shown in *Green Book* Exhibit 9-98.

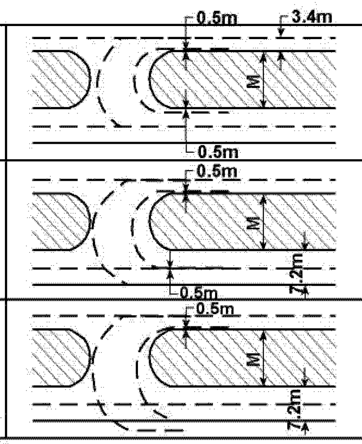
Loons to Assist Vehicles in Completing U-turn Maneuvers

A common problem associated with accommodating U-turn maneuvers at unsignalized median openings is the difficulty of larger vehicles to negotiate U-turns along cross-sections with narrow medians. This situation often affects the operation and safety of commercial vehicles that typically require more space in order to perform a U-turn maneuver. One possible solution to this problem is the construction of a loon. Loons are defined as expanded paved aprons opposite a median crossover. Their purpose is to provide additional space to facilitate the larger turning path of commercial vehicles along narrow medians. Figure C-19 presents a typical loon design. Where a large truck is used as the design vehicle for a median opening and a median width of 21 to 31 m (70 to 100 ft) cannot be provided, consideration should be given to providing a loon.

Several unsignalized median openings with loons were evaluated as part of this research. No specific problems related to loon operations were noted at these sites. Specifically, while median opening Type 2c was found to have a higher average median opening accident rate than median opening Type 2a, the individual accident patterns at these sites were reviewed; it was confirmed that the accidents at median openings of Type 2c did not involve trucks and were not related to loon usage. Although the sample size is very limited, there is no indication that provision of loons or their use by large trucks leads to safety problems. At the same time, there are not sufficient data to determine whether the provision of loons provides safety benefits.

Based on a study by Sisiopiku and Aylsworth-Bonzelet (*55, 56*), Table C-3 presents recommended loon widths for

TYPE OF MANEUVER	M - MIN. WIDTH OF MEDIAN (m) FOR DESIGN VEHICLE						
	P	WB-12	SU	BUS	WB-15	WB-18	TDT
	LENGTH OF DESIGN VEHICLE (m)						
	5.7	15.0	9.0	12.0	16.5	19.5	35.4
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



TYPE OF MANEUVER	M - MIN. WIDTH OF MEDIAN (ft) FOR DESIGN VEHICLE						
	P	WB-40	SU	BUS	WB-50	WB-60	TDT
	LENGTH OF DESIGN VEHICLE (ft)						
	19	50	30	40	55	65	118
INNER LANE TO INNER LANE	30	61	63	63	71	71	101
INNER LANE TO OUTER LANE	18	49	51	51	59	59	89
INNER LANE TO SHOULDER	8	39	41	41	49	49	79

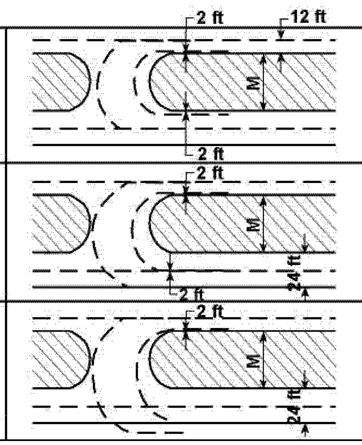


Figure C-18. AASHTO minimum median widths to accommodate U-turns (3).

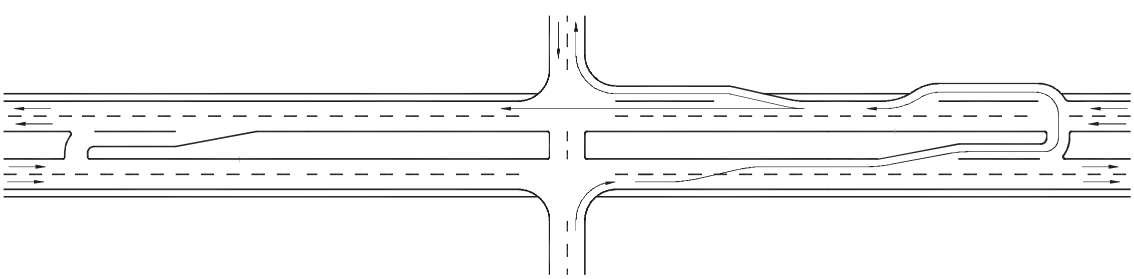


Figure C-19. Typical loon design at a directional median opening (55, 56).

TABLE C-3 Recommended loon widths for four-lane divided roadways (*55, 56*)

Median width (m)	Type of design vehicle					
	P	SU	BUS	WB-12	WB-15	WB-18
	Length of design vehicle (m)					
	5.7	9.0	12.0	15.0	16.5	19.5
	Width of loon (m)					
0	5	15	15	15	18	18
5	0	10	10	10	13	13
10	0	5	5	5	8	8
15	0	0	0	0	3	3
20	0	0	0	0	0	0

NOTE: Loon width equal to 0 indicates that the standard shoulder width is sufficient.

four-lane divided roadways. Usually, loons are not needed on six-lane divided highways; usually a paved shoulder provides all the additional width needed for U-turns by large trucks.

Median Opening Types

The four key factors used to classify or describe the design of a median opening are:

- *Type of geometry*—determines which movements are possible at a median opening. Conventional median openings typically permit all movements, while directional median openings may restrict certain movements.
- *Degree of access served*—determines what movements need to be accommodated at a median opening and the number of potential conflict points a median opening will have. Access points at median openings may include either intersecting public roads or driveways.
- *Presence of left-turn lanes*—indicates whether or not a median opening has a left-turn lane.
- *Presence of loons*—indicates whether or not a median opening is accompanied by a loon.

Based on these four factors, median openings can be classified based on their design characteristics as follows:

- Type of geometry (traffic movements permitted)
  - conventional (all movements permitted)
  - directional
- Degree of access served
  - U-turn only (midblock median opening)
  - access on one side (at three-leg intersection)
  - access on two sides (at four-leg intersection)
- Presence of left-turn lane
  - no left-turn lane present
  - left-turn lane present
- Presence of loon
  - no loon present
  - loon present

Drawings illustrating each of the median opening types, along with their advantages and disadvantages of each, are presented in the preceding section of these guidelines (see Figures C-3 through C-17).

METHODOLOGY FOR COMPARING THE EXPECTED SAFETY PERFORMANCE OF MEDIAN OPENING DESIGN ALTERNATIVES

This section presents a methodology for comparing the expected safety performance of median opening design alternatives. An overview of the methodology is presented first, followed by a detailed discussion of the methodology and two examples with sample calculations.

Overview of Methodology

The methodology for comparing the expected safety performance of median opening design alternatives consists of five logically sequenced steps as follows:

Step 1: Select median opening design alternatives
Step 2: Enter all turning volumes
Step 3: Enter the average non-intersection accident rate for the major road
Step 4: Calculate the accident rate for each median opening design alternative
Step 5: Compare accident rates for each median opening design alternative

Methodology

Step 1: Select median opening design alternatives

Typically, highway agencies are faced with selecting the most appropriate median opening design from a number of alternatives. In Step 1, each of the possible median opening design alternatives are identified. Note that an alternative may be an individual median opening design or may include a combination of median opening designs. For example, at a three-leg intersection, a highway agency may be considering the following alternatives:

- conventional median opening
- directional median opening

- directional median opening in combination with a directional midblock median opening located near the intersection.

Alternative 1: ______________________________

Alternative 2: ______________________________

Alternative 3: ______________________________

Step 2: Enter all turning volumes

Turning volumes—actual or estimated—for all possible turning movements must be provided. Figure C-20 illustrates all possible turning volumes at a four-leg intersection. If the median opening design alternative under consideration is a three-leg or midblock median opening, enter a zero for those turning volumes that do not apply.

Some median openings, such as a three-leg median opening or a directional median opening, will include only a portion of these turning volumes since not all turning movements are accommodated.

Enter all turning volumes for the median opening design alternatives considered:

Volume A
(Major-road U-turns in Direction 1) = ___ (veh/day)
Volume B
(Major-road U-turns in Direction 2) = ___ (veh/day)
Volume C
(Major-road left turns in Direction 1) = ___ (veh/day)
Volume D
(Major-road left turns in Direction 2) = ___ (veh/day)
Volume E
(Minor-road left turns in Direction 3) = ___ (veh/day)
Volume F
(Minor-road left turns in Direction 4) = ___ (veh/day)
Volume G
(Minor-road throughs in Direction 3) = ___ (veh/day)
Volume H
(Minor-road throughs in Direction 4) = ___ (veh/day)
Total turning volume = ___ (veh/day)

Step 3: Enter the average non-intersection accident rate for the major road

If any of the alternatives identified in Step 1 represents a combination of median opening designs, the average non-intersection accident rate for the major road is needed. This may be obtained from actual accident data or may be estimated based on historical accident experience or engineering judgment. In the absence of any reliable site-specific estimate, NCHRP Report 282 (*22*) suggests 2.90 accidents per million vehicle-miles is an average non-intersection accident rate for all four-lane divided suburban highways.

Non-intersection accident
rate for the major road = _________ (acc/MVM)

Step 4: Calculate the accident rate for each median opening design alternative

The accident rate for each median opening design alternative consists of at least one of the following components:

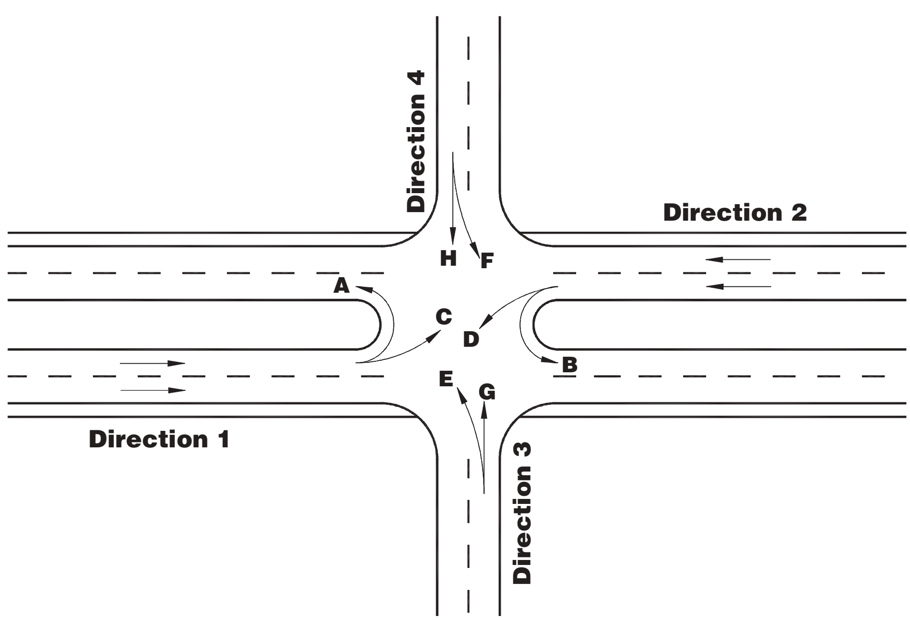


Figure C-20. Turning movements at a four-leg intersection.

- *Accident rate for each individual median opening*—For median opening design alternatives that consist of a single median opening, this is the only accident rate that needs to be computed. For median opening design alternatives that consist of a combination of median openings, this accident rate must be computed for each individual median opening that makes up the combination.
- *Accident rate for exposure due to additional travel distance*—For combinations of median openings, vehicles often travel an additional distance along the major road to complete their turning maneuver. This additional travel distance must be accounted for when computing the estimated safety performance of the combination of median openings. Therefore, the accident rate for the exposure due additional travel distance must be computed as well.

The equations for calculating each accident rate are presented below. Each equation utilizes Table C-4, which presents median opening accident rates by geometry type (conventional vs. directional) and number of intersection legs (midblock vs. three-leg vs. four-leg).

Step 4a: Calculate the accident rate for each individual median opening

The accident rate for each median opening can be estimated by the following equation:

$$Accident\ Rate(acc/yr) = \frac{[AR]acc}{10^6\ veh} \times \frac{[TV]veh}{day} \times \frac{365\ days}{yr}$$

where:

AR = accident rate from Table C-2
TV = sum of all turning volumes through median opening

For combinations of median openings, repeat this step for each individual median opening.

Step 4b: Calculate the accident rate for exposure due to additional travel distance

The accident rate for the exposure related to additional travel distance can be estimated by the following equation:

$$Accident\ Rate(acc/yr) = \frac{[AR_{mr}]acc}{10^6\ veh\text{-}mi} \times (2 \times d) \times \frac{[TV]veh}{day} \times \frac{365\ days}{yr}$$

where:

AR_{mr} = average non-intersection accident rate for major road
TV = sum of all turning volumes traveling additional distance
d = distance between midblock median opening and intersection (mi)

Step 4c: Calculate the total accident rate for each median opening design alternative

For alternatives that consist of a single median opening, the total accident rate is equal to the accident rate of that individual median opening, as computed in Step 4a.

For alternatives that consist of a combination of median openings, the total accident rate is equal to the accident rates for each individual median opening, as computed in Step 4a, and the accident rate for exposure related to additional travel distance, as computed in Step 4b.

Alternative 1: ____________________

Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (due to exposure) = ___ (acc/yr)
Total accident rate = ___ (acc/yr)

Alternative 2: ____________________

Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (due to exposure) = ___ (acc/yr)
Total accident rate = ___ (acc/yr)

Alternative 3: ____________________

Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (individual median opening) = ___ (acc/yr)

TABLE C-4 Median opening accident rates by geometry type and number of intersection legs at urban sites

Median opening type	Median opening accident rate (accidents per 10^6 turning vehicles)
Directional Midblock	0.29
Conventional 3-leg	2.69
Directional 3-leg	1.40
Conventional 4-leg	3.01
Directional 4-leg	2.57

Accident rate (individual median opening) = ___ (acc/yr)
Accident rate (due to exposure) = ___ (acc/yr)
Total accident rate = ___ (acc/yr)

Step 5: Compare accident rates for each median opening design alternative

The final step in the methodology is to compare the accident rates for each median opening design alternative. If one alternative has a substantially lower accident rate than the other alternative(s), that alternative may be a preferable median opening design from a safety standpoint. However, the alternatives should also be compared from an operational standpoint. For example, if one alternative accommodates fewer turning movements than another alternative, selecting that alternative may have a negative impact on the traffic operational performance of the arterial corridor.

Example 1: Comparison of the safety performance of conventional and directional median openings at three-leg intersections

Step 1: Select median opening design alternatives

Alternative 1: Conventional median opening at a three-leg intersection

Alternative 2: Directional median opening at a three-leg intersection in combination with a directional midblock median opening

Figure C-21 illustrates Alternatives 1 and 2. In Alternative 2, the directional median opening at the three-leg intersection accommodates vehicles making left-turn maneuvers from the major road onto the minor road and vehicles making U-turns in Direction 2 of the major road. Left-turn vehicles on the minor road and U-turn vehicles in Direction 1 of the major road must use the directional midblock median opening to complete their turning maneuvers.

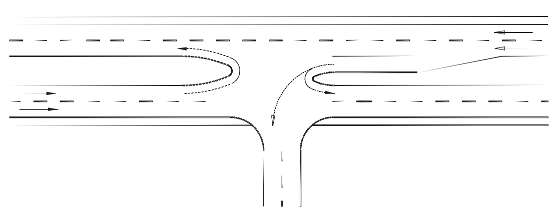
Step 2: Enter all turning volumes

Enter all turning volumes for the median opening design alternatives considered:

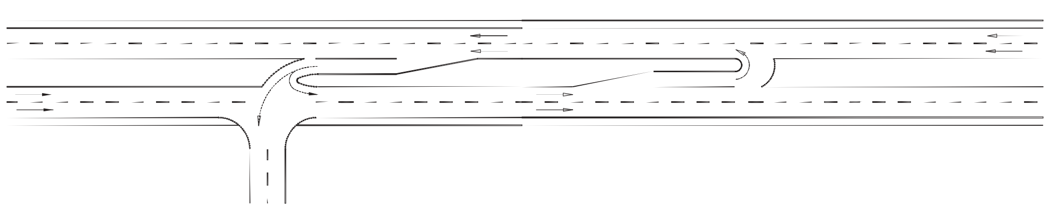
Volume A
(Major-road U-turns in Direction 1) = 25 veh/day
Volume B
(Major-road U-turns in Direction 2) = 25 veh/day
Volume C
(Major-road left turns in Direction 1) = N/A
Volume D
(Major-road left turns in Direction 2) = 225 veh/day
Volume E
(Minor-road left turns in Direction 3) = 225 veh/day
Volume F
(Minor-road left turns in Direction 4) = N/A
Volume G
(Minor-road throughs in Direction 3) = N/A
Volume H
(Minor-road throughs in Direction 4) = N/A
Total turning volume = 500 veh/day

Step 3: Enter the average non-intersection accident rate for the major road

Non-intersection accident rate for the major road = 2.90 acc/MVM (from NCHRP Report 282)



a) Conventional Median Opening at Three-Leg Intersection (Type 3b)



b) Directional Median Opening For Left Turns From Major Road at Three-Leg Intersection With Directional Midblock Median Opening (Type 4a + Type 2b)

Figure C-21. Conventional and directional median openings at three-leg intersection.

Step 4: Calculate the accident rate for each median opening design alternative

For Alternative 1, only the accident rate for a conventional median opening at a three-leg intersection needs to be computed.

For Alternative 2, the accident rates for a directional median opening at a three-leg intersection, a directional midblock median opening, and the exposure due to additional travel distance need to be computed.

Step 4a: Calculate the accident rate for each individual median opening

Conventional three-leg:

The accident rate for a conventional median opening at a three-leg intersection is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{2.69\ acc}{10^6\ veh} \times \frac{500\ veh}{day} \times \frac{365\ days}{yr} = 0.49\ acc/yr$$

From Table C-2, the median opening accident rate for a conventional three-leg median opening is 2.69 accidents per million turning vehicles. The total turning volume for this median opening is 500 veh/day, since all turning movements are permitted.

Directional three-leg:

The accident rate for a directional median opening at a three-leg intersection is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{1.40\ acc}{10^6\ veh} \times \frac{250\ veh}{day} \times \frac{365\ days}{yr} = 0.13\ acc/yr$$

From Table C-2, the median opening accident rate for a directional three-leg median opening is 1.40 accidents per million turning vehicles. The total turning volume for this median opening is 250 veh/day, since the only turning movements permitted include left turns from the major road onto the minor road (Direction 2) and U-turns on the major road in Direction 2.

Directional Midblock:

The accident rate for a directional midblock median opening is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{0.23\ acc}{10^6\ veh} \times \frac{250\ veh}{day} \times \frac{365\ days}{yr} = 0.02\ acc/yr$$

From Table C-2, the median opening accident rate for a directional midblock median opening is 0.23 accidents per million turning vehicles. The total turning volume for this median opening is 250 veh/day, since the midblock median opening accommodates major-road U-turns in Direction 1 and left turns from the minor road (Direction 4).

Step 4b: Calculate the accident rate for exposure due to additional travel distance

In this example, the directional midblock median opening is assumed to be located 0.2 mi from the three-leg intersection. Thus, the accident rate for the exposure related to additional travel distance is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{2.90\ acc}{10^6\ veh\text{-}mi} \times (2 \times 0.2\ mi) \times \frac{250\ veh}{day} \times \frac{365\ days}{yr} = 0.11\ acc/yr$$

From NCHRP Report 282, the average non-intersection accident rate for a four-lane divided highway is 2.90 accidents per million-vehicle-miles of travel. The total number of vehicles traveling the additional distance is equal to the total turning volume through the directional median opening, which is 250 veh/day.

Step 4c: Calculate the total accident rate for each median opening design alternative

Alternative 1: Conventional Median Opening at a Three-Leg Intersection

Accident rate (conventional three-leg)	= 0.49 acc/yr
Accident rate (individual median opening)	= ___ (acc/yr)
Accident rate (individual median opening)	= ___ (acc/yr)
Accident rate (due to exposure)	= ___ (acc/yr)
Total accident rate	= 0.49 acc/yr

Alternative 2: Combination of Directional Median Opening at a Three-Leg Intersection and a Directional Midblock Median Opening

Accident rate (directional three-leg)	= 0.13 acc/yr

Accident rate
(directional midblock) = 0.02 acc/yr
Accident rate
(individual median opening) = ___ (acc/yr)
Accident rate (due to exposure) = 0.11 acc/yr
Total accident rate = 0.26 acc/yr

Step 5: Compare accident rates for each median opening design alternative

Alternative 1 = 0.49 acc/yr
Alternative 2 = 0.26 acc/yr

In this example, the combination of directional median openings (Alternative 2) represents a 47% reduction in accident rate over the conventional median opening at a three-leg intersection (Alternative 1).

Example 2: Comparison of the safety performance of conventional and directional median openings at four-leg intersections

Step 1: Select median opening design alternatives

Alternative 1: Conventional median opening at a four-leg intersection

Alternative 2: Directional median opening at a four-leg intersection in combination with two directional midblock median openings

Figure C-22 illustrates Alternatives 1 and 2. In Alternative 2, the directional median opening at the four-leg intersection accommodates vehicles making left-turn maneuvers from the major road onto the minor road and vehicles making U-turns on the major road. Left-turn vehicles from the minor road approaches must use the directional midblock median openings to complete their turning maneuvers.

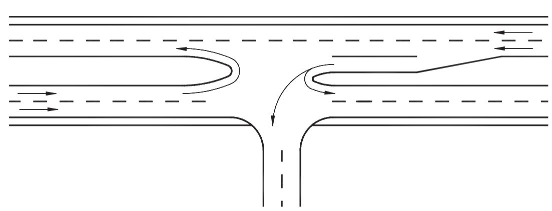
Step 2: Enter all turning volumes

Enter all turning volumes for the median opening design alternatives considered:

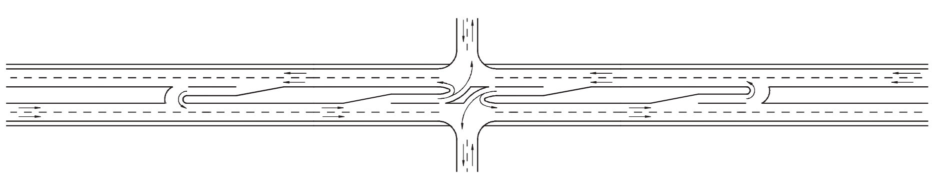
Volume A
(Major-road U-turns in Direction 1) = 40 veh/day
Volume B
(Major-road U-turns in Direction 2) = 40 veh/day
Volume C
(Major-road left turns in Direction 1) = 180 veh/day
Volume D
(Major-road left turns in Direction 2) = 180 veh/day
Volume E
(Minor-road left turns in Direction 3) = 180 veh/day
Volume F
(Minor-road left turns in Direction 4) = 180 veh/day
Volume G
(Minor-road throughs in Direction 3) = 100 veh/day
Volume H
(Minor-road throughs in Direction 4) = 100 veh/day
Total turning volume = 1,000 veh/day

Step 3: Enter the average non-intersection accident rate for the major road

Non-intersection accident
rate for the major road = 2.90 acc/MVM
(from NCHRP Report 282)



a) Conventional Median Opening at Four-Leg Intersection (Type 5b)



b) Directional Median Opening Four-Leg Intersection With Two Directional Midblock Median Openings (Type 2b + Type 6a + Type 2b)

Figure C-22. Conventional and directional median openings at four-leg intersection.

Step 4: Calculate the accident rate for each median opening design alternative

For Alternative 1, only the accident rate for a conventional median opening at a four-leg intersection needs to be computed.

For Alternative 2, the accident rates for a directional median opening at a four-leg intersection, two directional midblock median openings, and the exposure due to additional travel distance need to be computed.

Step 4a: Calculate the accident rate for each individual median opening

Conventional four-leg:

The accident rate for a conventional median opening at a four-leg intersection is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{3.01\,acc}{10^6\ veh} \times \frac{1000\,veh}{day} \times \frac{365\ days}{yr} = 1.10\ acc/yr$$

From Table C-2, the median opening accident rate for a conventional four-leg median opening is 3.01 accidents per million turning vehicles. The total turning volume for this median opening is 1,000 veh/day, since all turning movements as well as through movement on the minor road are permitted.

Directional four-leg:

The accident rate for a directional median opening at a four-leg intersection is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{2.57\,acc}{10^6\ veh} \times \frac{440\,veh}{day} \times \frac{365\ days}{yr} = 0.41\ acc/yr$$

From Table C-2, the median opening accident rate for a directional four-leg median opening is 2.57 accidents per million turning vehicles. The total turning volume for this median opening is 440 veh/day, since the only turning movements permitted include left turns from the major road onto the minor road and U-turns on the major road.

Directional Midblocks:

The accident rate for each of the directional midblock median openings is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{0.23\,acc}{10^6\ veh} \times \frac{280\,veh}{day} \times \frac{365\ days}{yr} = 0.02\ acc/yr$$

From Table C-2, the median opening accident rate for a directional midblock median opening is 0.23 accidents per million turning vehicles. The total turning volume for each median opening is 280 veh/day, since each median opening accommodates left-turn maneuvers from one of the minor-road approaches.

Step 4b: Calculate the accident rate for exposure due to additional travel distance

In this example, each directional midblock median opening is assumed to be located 0.2 mi from the four-leg intersection. Thus, the accident rate for the exposure related to additional travel distance is computed as follows:

$$Accident\ Rate(acc/yr) = \frac{2.90\,acc}{10^6\ veh\text{-}mi} \times (2 \times 0.2\ mi) \times \frac{560\,veh}{day} \times \frac{365\ days}{yr} = 0.24\ acc/yr$$

From NCHRP Report 282, the average non-intersection accident rate for a four-lane divided highway is 2.90 accidents per million-vehicle-miles of travel. The total number of vehicles traveling the additional distance is equal to the total turning volumes through both directional median openings, which is 560 veh/day.

Step 4c: Calculate the total accident rate for each median opening design alternative

Alternative 1: Conventional Median Opening at a Four-Leg Intersection

Accident rate (conventional four-leg)	= 1.10 acc/yr
Accident rate (individual median opening)	= ___ (acc/yr)
Accident rate (individual median opening)	= ___ (acc/yr)
Accident rate (due to exposure)	= ___ (acc/yr)
Total accident rate	= 1.10 acc/yr

Alternative 2: Combination of Directional Median Opening at a Four-Leg Intersection and Two Directional Midblock Median Openings

Accident rate (directional four-leg)	= 0.41 acc/yr
Accident rate (directional midblock)	= 0.02 acc/yr
Accident rate (directional midblock)	= 0.02 acc/yr
Accident rate (due to exposure)	= 0.24 acc/yr
Total accident rate	= 0.69 acc/yr

Step 5: Compare accident rates for each median opening design alternative

Alternative 1 = 1.10 acc/yr
Alternative 2 = 0.69 acc/yr

In this example, the combination of directional median openings (Alternative 2) represents a 32% reduction in accident rate over the conventional median opening at a four-leg intersection (Alternative 1).

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation