Safety of U-Turns at Unsignalized Median Openings on Urban and Suburban Arterials

Ingrid B. Potts
Senior Traffic Engineer
Midwest Research Institute
425 Volker Blvd.
Kansas City, MO 64110-2299
Tel: (816) 360-5284
Fax: (816) 561-6557
ipotts@mriresearch.org

Herbert S. Levinson
Transportation Consultant
40 Hemlock Road
New Haven, CT 06515
Tel: (203) 389-2092
hslevinson@aol.com

Douglas W. Harwood
Principal Traffic Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, MO 64110-2299
Tel: (816) 360-5336
Fax: (816) 561-6557
dharwood@mriresearch.org

Jerome Gluck
Vice President
Urbitran Associates, Inc.
71 W 23rd Street
New York, NY 10010
Tel: (212) 366-6200
Fax: (212) 366-6214
jerryg@urbitran.com

Safety of U-Turns at Unsignalized Median Openings on Urban and Suburban Arterials

by

Ingrid B. Potts, Herbert S. Levinson, Douglas W. Harwood, and Jerome Gluck

ABSTRACT. Many state and local transportation agencies install nontraversable medians on multilane arterials to improve safety and travel times and to better manage local access. Because nontraversable medians restrict direct left-turn access to and from adjacent developments, traffic destined for these locations must use alternate routes, some of which may involve making U-turns at nearby median openings—a movement often referred to as an indirect left turn.

NCHRP Project 17-21, "Safety of U-Turns at Unsignalized Median Openings," was conducted to further assess the safety effects of U-turn volumes. This paper presents key findings, along with the access management applications, from that research. It includes a summary of key literature, presents a detailed classification scheme for median openings, summarizes the results of comprehensive field studies, and identifies several highway planning implications.

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.

INTRODUCTION

Many state and local transportation agencies provide, or are considering, nontraversable medians on multilane arterials to improve safety, reduce travel time, and better manage access. Such medians limit direct left-turn access to and from land developments and require traffic entering or leaving these locations to use alternate routes. These alternate routes may involve making U-turns at nearby median openings—a movement often referred to as an indirect left turn. Two states—Michigan and New Jersey—have had policies regarding indirect left turns for many years. In Michigan, indirect left turns are used along arterials with wide medians, where left turns are prohibited at signalized intersections. In New Jersey, "jug handles" are used along divided arterials with narrow medians to prohibit left turns at signalized intersections. In recent years, indirect left turns have been provided in Florida along six-lane arterials with narrow medians. As more attention is given to access management, it is likely that more state and local highway agencies will consider providing indirect left turns along divided roadways.

The need to address the safety effects of U-turns, especially at unsignalized intersections, is timely. This paper presents key findings from NCHRP Project 17-21, "Safety of U-Turns at Unsignalized Median Openings," which documented the safety performance and operational impacts of U-turns at median openings (*1*). It summarizes reported safety effects of various left-turn treatments (including indirect left turns), documents the results of a highway agency survey, presents a classification of typical median opening designs, describes the data collection and analysis effort, and presents the research findings and their application for access management.

LITERATURE REVIEW

A literature review was conducted to document current knowledge of location, spacing, and safety of median openings, including the safety effects of U-turn maneuvers and left-turn lanes. Key issues from the literature review are summarized below.

Safety of Median Openings

Two published research studies have specifically addressed the safety performance of divided highway intersections: A 1953 California study of 150 at-grade intersections on 290 km (180 mi) of divided highways found that low-crossroad-volume intersections have higher accident rates per crossroad vehicle than do high-crossroad-volume intersections (*2*). The following relationship was reported:

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

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 suggests 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.

A 1964 Ohio study at 316 at-grade intersections on divided highways with partial or no control of access, plotted annual accident occurrence as a fraction of divided highway and crossroad ADT *(3)*. Accident frequency was more sensitive to crossroad traffic than to divided highway traffic.

Safety of Left-Turn Lanes

The safety impacts of installing left-turn lanes have been the focus of many studies. The Institute of Transportation Engineering cites an average accident reduction of 30 to 65 percent at unsignalized intersections (*4*). Gluck et al. reported reductions in accident rates of 18 to 77 percent based on 59 studies *(5)*. Foody and Richardson found that accident rates decreased by 76 percent at unsignalized intersections *(6)*.

Harwood et al. gathered accident data for 280 improved intersections and 300 similar unimproved intersections *(7)*. The following reductions in accidents were found.

Unsignalized	**Rural**	**Urban**
3-leg	44%	33%
4-leg	28%	27%

When implemented with additional safety measures, left-turn lanes are very effective in increasing safety. Hauer 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 *(8)*. When the channelization was painted, rather than raised, accidents decreased only by 15, 30, and 50 percent in urban, suburban, and rural areas, respectively.

Safety of Medians

An extensive body of literature has addressed the safety of raised medians and two-way left-turn lanes (TWLTLs). Research by Bonneson and McCoy in NCHRP 395, "Capacity and Operational Effects of Midblock Left-Turn Lanes," analyzed the relative operational and safety performance of highways that are undivided, divided by a raised median, or divided by a center two-way left-turn lane *(9)*. The report indicated that raised medians are the preferred midblock treatment from a safety perspective, and that they are generally similar to two-way left-turn lanes in their operational features. A comparison of seven accident models indicated that the raised medians have fewer expected accidents per year, except when traffic volumes are 10,000 veh/day or less.

NCHRP Report 420, *Impacts of Access Management Techniques*, presents a summary of individual studies that have analyzed the safety benefits of replacing TWLTLs with nontraversable medians on undivided highways *(5)*. 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 each median treatment. In 15 out of the 16 comparisons, the accident rates were reduced when a nontraversable median was installed in place of a TWLTL.

Indirect Left Turns and U-Turns

Indirect left turns, or U-turns, are used in several states as an alternative to direct left turns, mainly on six-lane roadways. In Florida, left-turn access from driveways and minor streets onto major arterials is prohibited; therefore, median openings are provided to accommodate indirect left turns. In Michigan, midblock median openings are provided on highways with wide medians (usually 40 ft or more).

Several studies have estimated the safety effects of U-turns as an alternative to left turns (*10-14*). NCHRP Report 420 (*5*) compares the results of these studies and reports an estimated 20 percent reduction in accident rate by replacing direct left turns from driveways with right-turn/U-turn treatments. Table 1 summarizes the difference in accident rate at unsignalized locations where direct left turns were replaced by U-turns. Reductions in the accident rate for study sites in Florida ranged from 18 to 22 percent; for study sites in Michigan, 15 to 61 percent. However, at locations where there were no traffic signals at nearby intersections, rates increased by 15 percent (only 11 bidirectional and 2 completely directional sites were compared).

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.

Limited research has been conducted to evaluate the safety and operation of loons. A recent study by Sisiopiku and Aylsworth-Bonzelet (*15*,*16*) evaluated the operation, placement, and safety of existing loons at directional median openings in western Michigan. 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. A safety analysis indicated that directional crossovers with loons experienced a high percentage of fixed object and side-swipe crashes. Further research is needed to address the safety of loons and to develop guidelines for their design and placement.

DESIGN POLICIES AND PRACTICES

As part of NCHRP Project 17-21, state and local highway agencies were surveyed to obtain information on their median-related design practices and policies. Survey questionnaires were mailed to 50 state highway agencies, 94 cities, and 15 counties. The response rate was 70 percent for state highway agencies, 28 percent for local highway agencies, and 41 percent overall. Information was obtained on median location and design, treatment of U-turns at median openings, median and roadway widths to accommodate U-turn maneuvers, traffic operational and safety problems, and mitigation measures for safety problems. Key findings are summarized below.

Ten of the 65 survey respondents (16 percent) indicated that they have a formal policy for U-turn maneuvers. Most of these agencies rely primarily on geometric design policies in the AASHTO *Green Book* (*17*) or some variation of AASHTO policy in their own guidelines. Most of the respondents have formal policies concerning when to prohibit U-turns at median openings. Some agencies without formal policies have informal guidelines on where to permit or prohibit U-turns, such as:

- Permitted only at locations having sufficient roadway width for maneuver
- Prohibited based on accident rate or safety problems
- Prohibited where they would create a substantial number of conflicts
- Prohibited in some school zones
- Prohibited to relieve congestion at median openings
- Permitted at unsignalized median openings where a specific need is identified
- Prohibited where a need is identified through engineering judgment

TYPICAL MEDIAN OPENING DESIGNS

A key objective of the research was to identify and classify typical median opening designs used to accommodate U-turn maneuvers at unsignalized median openings. This classification system identifies how particular median openings function and where they are located relative to other elements of the highway system.

Classification of Median Openings

Median openings were classified by type of geometry, degree of access provided, presence of left-turn lanes, and presence of loons. Using these classification factors, the research focused on six basic categories of median openings with a total of 15 typical median opening designs:

1. Conventional midblock median openings
   - 1a—without left-turn lanes
   - 1b—with left-turn lanes
   - 1c—with left-turn lanes and loons
2. Directional midblock median openings
   - 2a—without left-turn lanes
   - 2b—with left-turn lanes
   - 2c—with left-turn lanes and loons
3. Conventional median openings at three-leg intersections
   - 3a—without left-turn lanes
   - 3b—with one left-turn lane
   - 3c—with two left-turn lanes
   - 3d—with two left-turn lanes and loons
4. Directional median openings at three-leg intersections
   - 4a—from major road onto cross street
   - 4b—from cross street onto major road
5. Conventional median opening at four-leg intersections
   - 5a—without left-turn lanes
   - 5b—with left-turn lanes
6. Directional median openings at four-leg intersections
   - 6a—from major road onto cross street

Figure 1 illustrates the 15 types of median opening designs represented by this classification system.

Combinations of Openings

Each of the typical median opening types identified above represents an individual median opening. In practice, combinations of various median opening designs are used to accomplish a particular goal. Eight typical combinations of median openings are presented in Table 2. For example, the first combination (Combination C1) is a direction 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:

$$\text{Combination C1} = \text{Type 6a} + \text{Type 2b} + \text{Type 6a} \qquad \textbf{(2)}$$

DATA COLLECTION AND ANALYSIS

Information on median opening designs were obtained from seven states. A list of approximately 10 to 20 corridors of varying lengths were obtained from highway agencies in Colorado, Georgia, Michigan, New Jersey, and New York. In Georgia, all of the corridors were located in Gwinnett County and were 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 corridors within Kansas and Missouri.

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.

Summary of Catalog Data

The database included 62 arterial corridors in the seven states. The corridors included 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 a total of 918 unsignalized median openings located in the 62 arterial corridors. Several sites, however, were excluded from the analysis, because they did not fit into any of the median opening types, U-turns were prohibited at the median openings, or they had an asymmetrical cross-section (i.e., three through lanes in one direction of travel and two in the other). Thus, a total of 806 unsignalized median openings were included in the analysis.

Data Collection and Analysis for Specific Median Openings

Three major data collection and analysis activities were conducted at existing median openings used for U-turns: field observational studies, accident studies, and analysis of traffic conflicts and driver behavior.

Field observational studies were conducted at four corridors in each of 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 based on median opening types and level of U-turn activity. Within each corridor, one intersection was selected for videotaping. The intersections were selected to cover the range of median opening types and median widths of interest. These studies involved videotaping one unsignalized median opening in each arterial corridor for periods of approximately 6 hr per site, including the evening peak period and two off-peak periods.

The videotapes were used (1) to obtain counts of turning movement volumes at the intersections and (2) to note traffic conflicts and undesirable driving behavior that may indicate 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 a human factors evaluation.

In addition, short 15- to 30-min turning movement counts were performed at other median openings in each corridor during the same time 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. Overall, 32 median openings were videotaped, and turning movement counts were obtained at 125 locations.

Accidents

Accident data were obtained from each of the participating highway agencies for a period of at least 5 years. A total of 7,717 median-opening-related accidents were identified at 668 median openings. Only 79 accidents (1.1 percent) were identified as involving U-turns. Since 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. It was evident from review of the accident data that many U-turn accidents are, in fact, coded as left-turn accidents. Thus, the database included 79 U-turn accidents (1.1 percent) and 1,293 left-turn accidents (16.8 percent) for a total of 1,372 U-turn-plus-left-turn accidents (17.8 percent). U-turn and left-turn accidents accounted for 9 percent of all midblock accidents, 18 percent of three-leg intersection accidents, and 23 percent of four-leg intersection accidents. They accounted for about 20 percent of the accidents at conventional intersections and 14 percent of the accidents at directional intersections.

KEY FINDINGS

Traffic volume data and turning movement counts, where available, were obtained for each median opening site. The total median accident rates were then developed by comparing the 5-year accident frequency with the median opening movements during the entire study period.

Accident Rates

Total median opening accident rates by median opening type are presented in Table 3. Accidents related to U-turn and left-turn maneuvers at unsignalized median openings are infrequent. Urban arterial corridors experience an average of 0.41 U-turn-plus-left-turn accidents per median opening per year; rural arterial corridors experience an average of 0.20 U-turn-plus-left-turn accidents per median opening per year.

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. Average median opening accident rates are slightly lower for conventional three-leg median openings than for conventional four-leg median openings.

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 opening accident rate at median openings with either no left-turn lane or only one left-turn lane; however, this result is counterintuitive, and the data are based on 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 with left-turn lanes.

The accident rate for four-leg intersections differs from findings reported in the literature that shows left-turn lanes at unsignalized four-leg intersections have 30 to 65 percent fewer accidents.

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 too small to draw firm conclusions.

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.

Rates for Combinations of Median Openings

Comparisons between the safety of conventional and directional median openings must take into consideration the number of movements allowed through each median opening type. For example, the safety of a conventional median opening at a three-leg intersection should be compared to the safety of a directional median opening at a three-leg intersection in combination with two directional midblock median openings. Table 4 presents a comparison of the safety of conventional median openings at three- and four-leg intersections to the safety of directional median openings at three- and four-leg intersections in combination with directional midblock median openings. Directional median openings at three-leg intersections have about two-thirds as many accidents as the corresponding conventional intersection. Directional median openings at four-leg intersections have about 90 percent as many accidents as the corresponding conventional intersection.

APPLICATIONS FOR ACCESS MANAGEMENT

The specific application of U-turns at unsignalized and signalized intersections will depend on median width and the number of travel lanes along an arterial. Figure 2 illustrates the following examples of using U-turns as an alternative to direct left turns:

- Median openings can be provided for U-turning vehicles in advance (upstream) of signalized intersections. This avoids concentrating U-turns, or development-related traffic, at signalized intersections with cross streets.
- Left- and U-turns can be accommodated at signalized intersections. This requires a special phase for left and U-turns.
- Left- and U-turn maneuvers can be accommodated at median openings downstream of intersections (common treatment in Michigan). This makes it possible to prohibit all left turns at signalized intersections.

- Left turns can be provided by means of "jug handles" at signalized intersection. This also makes it possible to eliminate the left turn phase.

Wide Medians on Multilane Arterials

Figure 3 illustrates an example of an indirect left-turn treatment for multilane arterials with wide medians. All left turns are prohibited at the signalized intersection; left-turn traffic is directed to median openings about 660 ft upstream and downstream of the signalized intersection where U-turn maneuvers are accommodated. Additional right-turn lanes are provided on all intersection approaches since the diversion of left turns results in increased right turns. Two advantages to this treatment are (1) overlapping left-turn movements on the cross street are eliminated and (2) two-phase traffic signal operation can be provided. This treatment should be applied consistently throughout the length of the arterial roadway to avoid driver confusion.

Conventional Medians on Six-Lane Arterials

Figure 4 illustrates an example of an indirect left-turn treatment on six-lane arterials with conventional medians. Left turns can be prohibited at signalized intersections and accommodated in advance of the intersection. This treatment is commonly used along wide suburban arterials.

Conventional Medians on Four-Lane Arterials

Four-lane arterials with conventional medians are usually too narrow to accommodate U-turn maneuvers, especially by larger vehicles, safely and comfortably. One possible solution is to construct a loon. Loons are defined as expanded paved aprons opposite a median opening. Their purpose is to provide additional space to facilitate the larger turning path of large vehicles along narrow medians. Figure 5 presents a typical loon design.

Table 5 presents recommended loon widths for four-lane divided arterials. For a median width of 5 m (16 ft), the loon width should be 10 to 13 m (33 to 43 ft). Ideally, loons should be placed where a significant number of U-turns by large vehicles are anticipated, or at regular intervals where space is available. In reality, land availability may be the determining factor in where loons are located.

CONCLUSIONS

The research indicates that indirect left-turn arrangements that involve U-turns can improve safety when accompanied by restricted left turns at nearby unsignalized intersections. Accidents related to U-turn and left-turn maneuvers at unsignalized median openings are infrequent. Urban arterial corridors experience an average of 0.41 U-turn-plus-left-turn accidents per median opening per year; rural arterial corridors experience an average of 0.20 U-turn-plus-left-turn accidents per median opening per year.

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. Average median opening accident rates are slightly lower for conventional three-leg median openings than for conventional four-leg median openings.

Where directional median openings are considered as alternatives to conventional median openings, two or more directional median openings are normally 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 to the single conventional media opening. Typical directional median opening designs at three-leg and four-leg urban intersections, used in combination with directional midblock median openings, reduce accident rates up to one-third as compared with conventional intersections. When left turns are prohibited at signalized intersections and replaced by indirect left turns (as in Michigan), even greater accident reductions have been reported.

Right-of-way requirements for multilane arterials should be sufficient to accommodate U-turns. Wide medians (as in Michigan) may permit prohibition of left turns at signalized intersections. Where this is not practical, conventional treatments may be used on six-lane arterials; however, provision of loons along four-lane arterials to accommodate U-turn maneuvers by trucks should be considered.

REFERENCES

1. Potts, I. B., D. W. Harwood, D. J. Torbic, K. Richard, J. Gluck, H. S. Levinson, P. Garvey, and R. Ghebrial, Final Report NCHRP Project 17-21, Midwest Research Institute, Kansas City, MO, 2004.

2. McDonald, J. W., "Relation Between Number of Accidents and Traffic Volume at Divided-Highway Intersections," *Bulletin 74*, Highway Research Board, 1953.

3. Priest, R. V., "Statistical Relationships Between Traffic Volume, Median Width, and Accident Frequency on Divided Highway Grade Intersections," *Highway Research News*, No. 13, Highway Research Board, June 1964.

4. *The Traffic Safety Toolbox: A Primer on Traffic Safety*, Institute of Transportation Engineers, Washington, DC, 1987.

5. Gluck, J., H. S. Levinson, and V. Stover, *Impacts of Access Management Techniques*, NCHRP Report 420, National Cooperative Highway Research Program, Transportation Research Board, 1999.

6. Foody, T. J., and W. C. Richardson, "Evaluation of Left Turn Lanes as a Traffic Control Device," Ohio Department of Transportation, 1973.

7. Harwood, D. W., K. M. Bauer, I. B. Potts, D. J. Torbic, K. R. Richard, E. R. K. Rabbani, E. Hauer, and L. Elefteriadou, *Safety Effectiveness of Intersection Left -and Right-Turn Lanes*, Report No. FHWA-RD-02-089, Federal Highway Administration, July 2002.

8. Hauer, E., "The Safety of Older Persons at Intersections," in *Transportation in an Aging Society: Improving Mobility and Safety for Older Persons, Volume 2, Special Report 218*, Transportation Research Board, 1988.

9. Bonneson, J .A., and P .T. McCoy, *Capacity and Operational Effects of Midblock Left-Turn Lanes*, NCHRP Report 395, National Cooperative Highway Research Program, Transportation Research Board, 1997.

10. Florida Department of Transportation, 1996.

11. Lu, J., S. Dissanayake, N. Castillo, and K. Williams, "Methodology to Quantify the Effects of Access Management on Roadway Operations and Safety," Florida Department of Transportation, 2000.

12. Kach, B., “The Comparative Accident Experience of Directional and Bi-Directional Signalized Intersections,” Michigan Department of Transportation, 1992.

13. Maki, R. E., “Directional Crossovers: Michigan’s Preferred Left-Turn Strategy,” presented at the 75th annual meeting of the Transportation Research Board, 1996.

14. Castronovo, S., P. W. Dorothy, M. C. Scheuer, and T. L. Maleck, et al., *The Operational and Safety Aspects of the Michigan Design for Divided Highways, Volume I*, Michigan State University College of Engineering, 1995.

15. Aylsworth-Bonzelet, L., and V. Sisiopiku, “The Operation and Design of Loons at Narrow Median Cross-Overs,” Technical Report to the Great Lakes Center for Truck and Transit Research, 1998.

16. Sisiopiku, V., and L. Aylsworth-Bonzelet, “Application of Loons at Directional Crossovers,” presented at the 82nd annual meeting of the Transportation Research Board, 2003.

17. American Association of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets*, Washington, DC, 2001.

LIST OF FIGURES

LIST OF TABLES

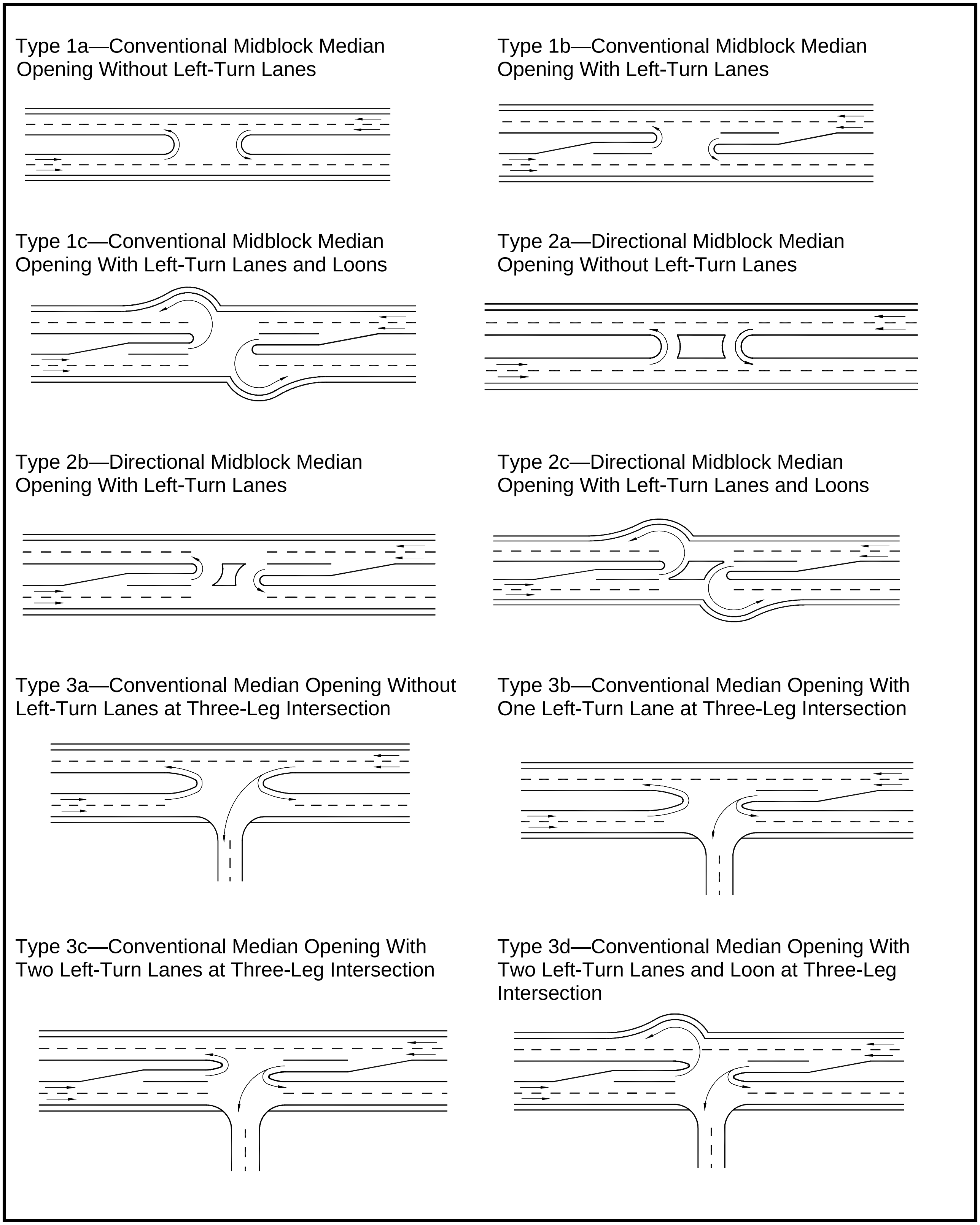
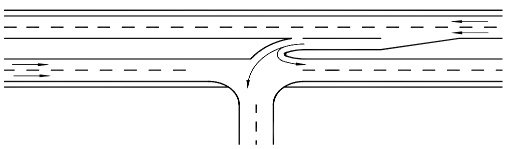
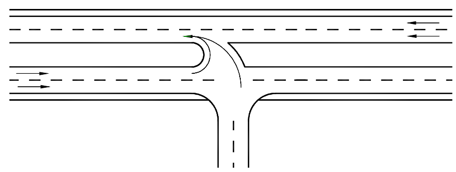


Figure 1. Classification of Typical Median Opening Designs

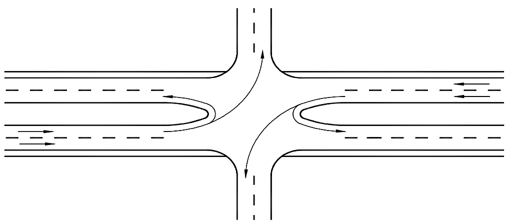
Type 4a—Directional Median Opening for Left Turns From Major Road at Three-Leg Intersection



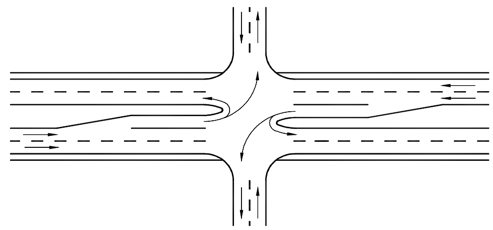
Type 4b—Directional Median Opening for Left Turns Onto Major Road at Three-Leg Intersection



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

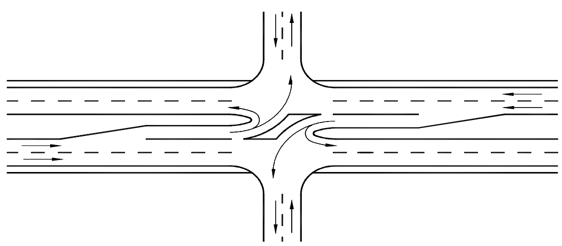
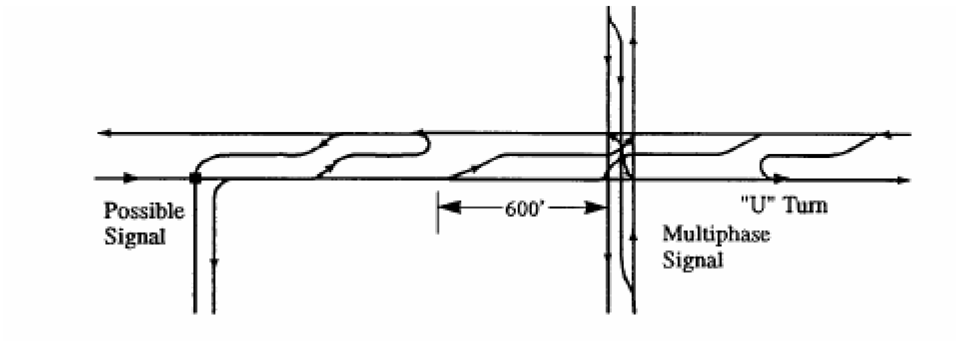
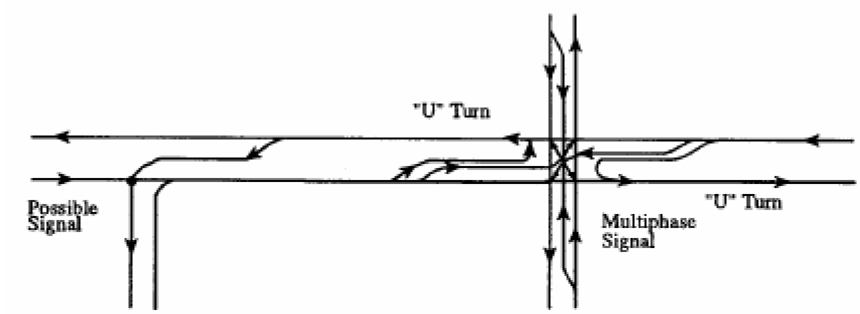


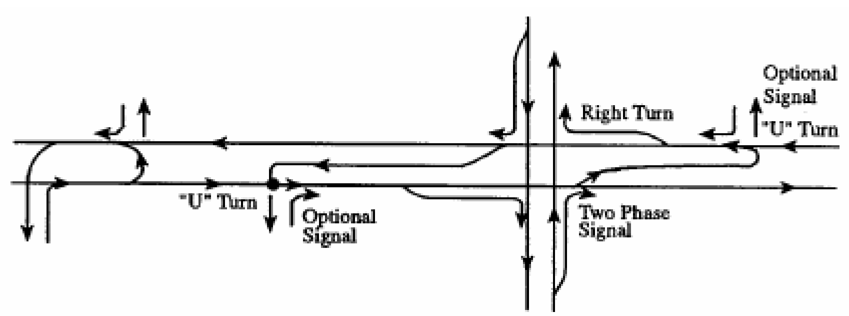
Figure 1. Classification of Typical Median Opening Designs (Continued)



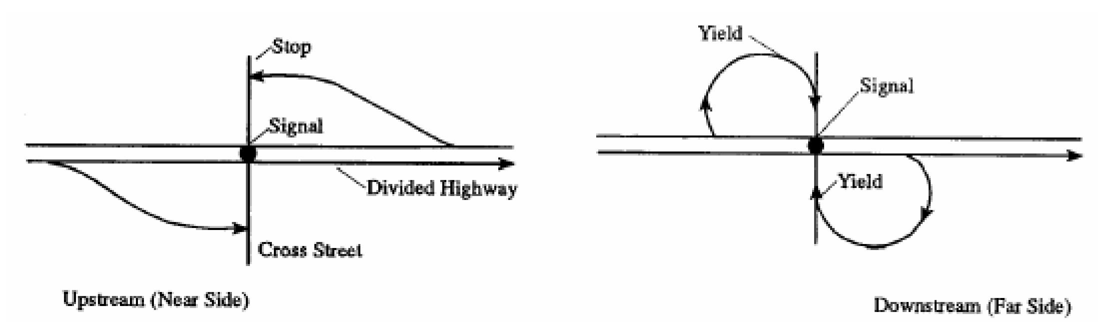
a) U-turn in advance of intersection (U-turn may be signalized)



b) U-turn at intersection



c) U-turn downstream of intersection (commonly used in Michigan)



d) "Jug handles" at signalized intersection

Figure 2. U-Turns as an Alternative to Direct Left Turns (5)

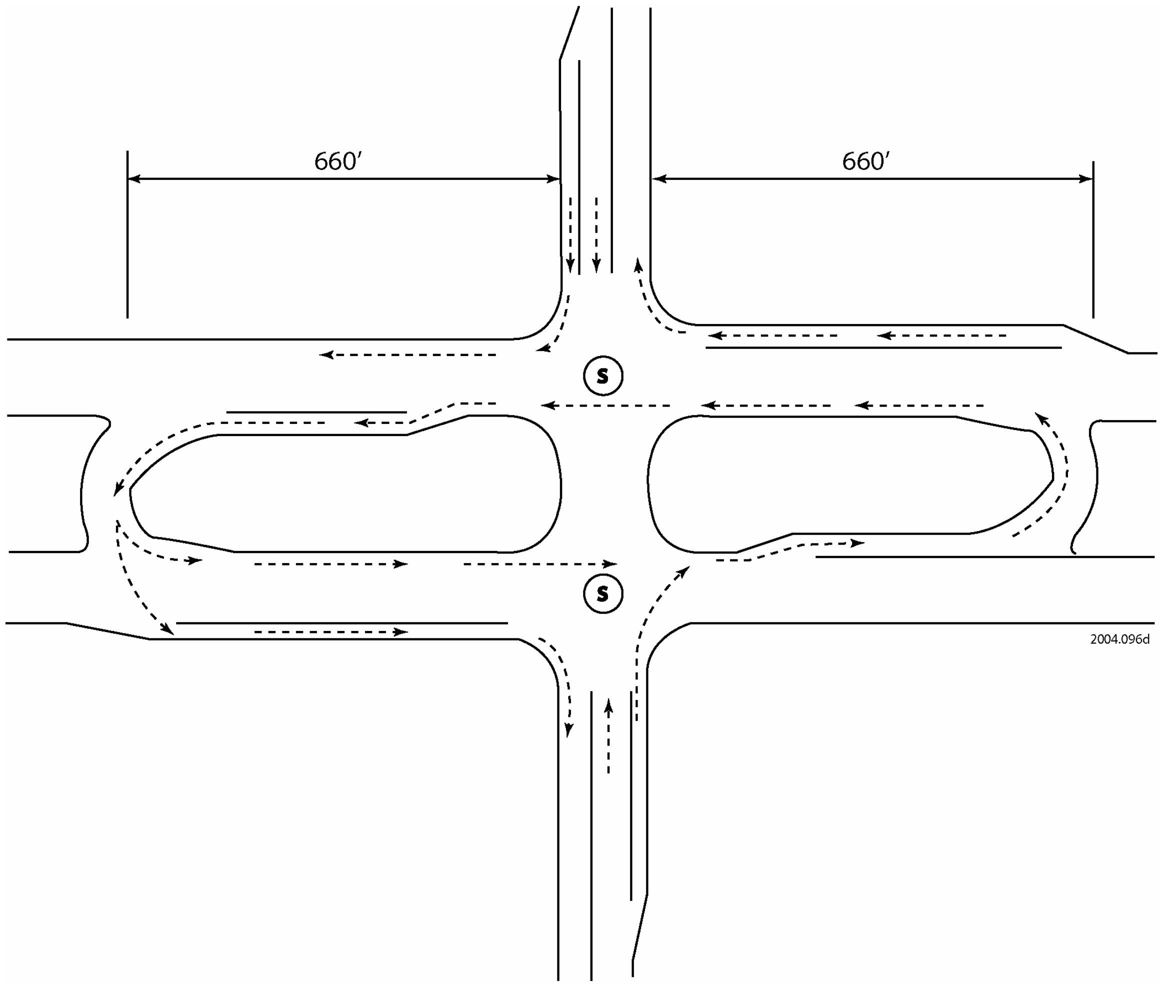


Figure 3. Indirect Left-Turn Alternative for Multilane Arterials With Wide Medians

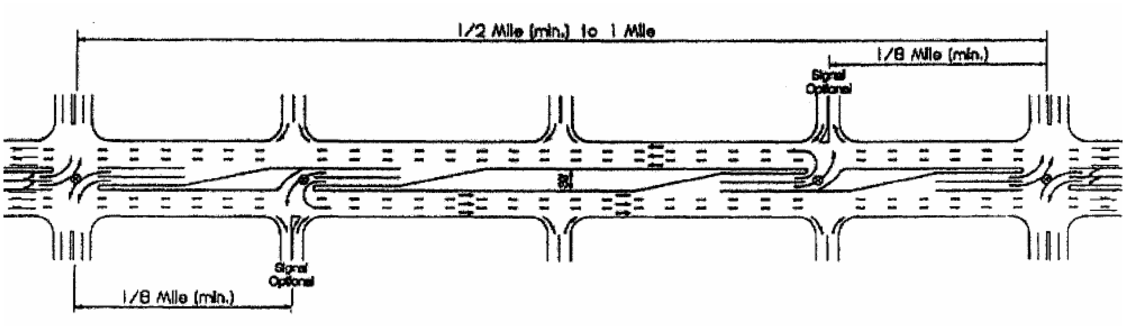


Figure 4. Left-turn/U-turn Lanes in Advance of Intersection

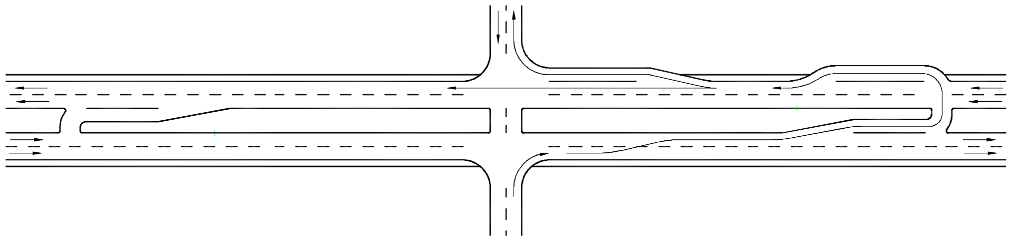


Figure 5. Typical Loon Design at a Directional Median Opening (15, 16)

TABLE 1. Accident Rate Differences—U-Turns as Alternate to Direct Left Turns

Location	Treatment	Difference in accident rate (%)
US-1, Florida (*10*)	Driveway left turns replaced by right-turn/U-turn	–22
Florida (*11*)	Left turns replaced by right-turn/U-turn	–18
Grand River Blvd Detroit, Michigan (*12*)	Bi-directional crossover replaced by directional crossover	–61
Michigan (*13*)	Bi-directional crossover replaced by directional crossover	–15
Michigan (*14*)	Bi-directional crossover replaced by directional crossover on unsignalized roadway segment	+14
	Bi-directional crossover replaced by directional crossover with nearby signalized intersections	–36 to 52
Michigan (*14*)	TWLTL replaced by directional crossover	–50

NOTE: Adapted from Ref *(5)*.

TABLE 2. Typical Combinations of Median Openings

Combination	Components	Cross street through traffic permitted?
C1	Type 6a + Type 2b + Type 6a	No
C2	Type 5b + Type 1b + Type 5b	Yes
C3	Type 5b + Type 2b + Type 5b	Yes
C4	Closed Type 5b + Type 2b + Closed Type 5b	No
C5	Closed Type 3a + Type 2b + Closed Type 3a	No
C6	Closed Type 5a + Type 1b + Closed Type 5a	No
C7	Closed Type 3a + Type 1b + Closed Type 3a	No
C8	Signalized Type 5a + Type 2b + Signalized Type 5a	No

NOTE: “Closed” refers to an intersection without a median opening.

TABLE 3. 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 4. Comparison of Accident Rates at Conventional and Direction Median Openings

	Conventional	Directional	Directional as % of conventional
3-leg intersection	Type 3b	Type 4a + Type 2b	
	2.46[a]	1.44 + 0.23 = 1.67[a]	68
4-leg intersection	Type 5b	Type 6a + Type 2b + Type 2b	
	3.34[a]	2.57 + 0.23 + 0.23 = 3.03[a]	91

[a] Accidents per 10^6 turning vehicles.

TABLE 5. Recommended Loon Widths for Four-Lane Divided Arterials (*15,16*)

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.