NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP Report 375

Median Intersection Design

Transportation Research Board
National Research Council

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report 375

Median Intersection Design

DOUGLAS W. HARWOOD
Midwest Research Institute
Kansas City, MO
and
MARTIN T. PIETRUCHA, MARK D. WOOLDRIDGE, and ROBERT E. BRYDIA
Pennsylvania Transportation Institute
University Park, PA
and
KAY FITZPATRICK
Texas Transportation Institution

Subject Areas

Highway and Facility Design
Highway Operations, Capacity and Traffic Control
Safety and Human Performance

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
Washington, D.C. 1995

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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

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

NCHRP REPORT 375

Project 15-14(2) FY'92

ISSN 0077-5614

ISBN 0-309-05704-3

L. C. Catalog Card No. 95-62224

Price $25.00

NOTICE

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

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

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

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

FOREWORD

By Staff
Transportation Research Board

This report describes the development of design guidelines for the selection of median widths for at-grade intersections on divided highways with partial or no control of access. It includes, as an Appendix, recommended revisions to the 1994 AASHTO Green Book, *A Policy on Geometric Design of Highways and Streets.* The contents of this report are therefore of immediate interest to highway and facility designers; highway-operations, capacity, and traffic-control personnel; and others concerned with safety and human performance. The report's conclusions are based on field observations of traffic operations at selected divided highway intersections; a statistical analysis of relationships between median width and intersection-accident experience using a statewide accident, geometric, and traffic volume data base; and the use of existing traffic simulation models.

Operational design of median widths and geometric configurations at intersections to meet the needs of rural and suburban traffic has long been a concern. As noted in AASHTO's *Policy on Geometric Design of Highways and Streets,* the width of medians at intersections on highways with partial or no access control is critical to their operation and safety.

Median-width research efforts have, for the most part, addressed freeway operations only. These efforts have provided a significant amount of information on cross-section design and optimum width. However, little or no research has been directed toward developing guidelines for median widths at intersections with partial or no access control.

Median width may pose operational problems in the vicinity of intersections for (1) left-turning traffic from the main roadway and (2) crossing or left-turning traffic from crossroads. These problems may be created or compounded by other factors, such as the expanse of pavement area, inadequate storage for turning or crossing vehicles, restricted sight distance at the intersection approaches, and violations of driver expectations for traffic movements (for example, drivers tend to become confused about intended operational characteristics of the multiple intersections encountered).

Currently, the focus of many transportation agencies is on the construction or recontruction of multilane facilities having partial or no access control. Because current design policy does not adequately address median widths or intersection treatments on these types of facilities, Midwest Research Institute was awarded NCHRP Project 15-14(2) to develop and recommend median-width parameters and design criteria for intersections on rural and suburban highways with partial or no access control.

Guidelines were to be developed for new and reconstructed facilities, considering at least the following: (1) Safety, (2) Traffic Operations, (3) Traffic Volumes, (4) Type of Traffic Control, (5) Design Speed of the Facility, and (6) Traffic Characteristics. Secondary issues included intersection configuration and spacing. The ultimate goal of the research was to develop recommended guidelines prepared in a format suitable for adoption by AASHTO. The proposed guidelines can be found in the Appendix at the end of this report; the report itself describes the research justifying the recommended guidelines.

The research found that at rural unsignalized intersections both accidents and undesirable driving behavior *decrease* as the median width increases. Conversely, at suburban signalized and unsignalized intersections, accidents and undesirable behavior *increase* as the median width increases. A more detailed description of the findings is outlined in the summary of findings at the beginning of the report, and the confirming research is detailed throughout the report.

CONTENTS

ACKNOWLEDGMENTS

The work reported herein was performed under NCHRP Project Panel 15-14(2) by Midwest Research Institute (MRI), Pennsylvania Transportation Institute (PTI), and Texas Transportation Institution (TTI). The work was performed in MRI's Center for Technology and Regional Development, directed by Dr. David L. Bodde.

Mr. Douglas W. Harwood, Principal Traffic Engineer at MRI, was the principal investigator of the research. Other MRI staff members who participated in the research included Ms. Karin M. Bauer, Dr. William D. Glauz, and Ms. Erin J. McGrane. The subcontract work at PTI was directed by Dr. Martin T. Pietrucha. Other PTI staff members who contributed to the work included Mr. Mark D. Wooldridge, Mr. Robert E. Brydia, and Dr. John M. Mason. The subcontract work at TTI was directed by Dr. Kay Fitzpatrick. Other TTI staff members who participated in the research included Mr. Torstein Lineau and Dr. Vergil Stover. Mr. Harwood, Dr. Pietrucha, Dr. Fitzpatrick, Mr. Wooldridge, and Mr. Brydia served as co-authors of this final report.

The research team received valuable assistance from the staffs of 10 state highway agencies who participated in the study: California, Illinois, Iowa, Kansas, Maryland, Missouri, New Jersey, Pennsylvania, Texas, and West Virginia.

We are also grateful to traffic engineers in 63 state and local highway agencies who responded to a questionnaire on their design practices and traffic operational and safety experience with at-grade intersections on divided highways.

MEDIAN INTERSECTION DESIGN

SUMMARY

The objectives of this research were to develop and recommend appropriate design policies, on the basis of operational and safety considerations, for median widths at rural and suburban divided highway intersections. The research scope addressed the design of the median width and related features of the median roadway for at-grade intersections on divided highways with partial or no control of access.

Median widths for divided highways are often selected primarily on the basis of safety conditions between intersections. The research was undertaken because knowledge of the effects of median widths on the operation and safety of the intersections along a divided highway is limited.

A field observational study of traffic operations was conducted at 40 selected divided highway intersections in 10 states. The selected intersections included rural, unsignalized intersections; suburban, unsignalized intersections; and suburban, signalized intersections all having various median widths. This study focused on specific types of undesirable driving behavior that were observed at divided highway intersections: drivers lining up their vehicles side by side rather than in single file; drivers stopping their vehicles in the median at an angle to, rather than perpendicular to, the major road; and drivers stopping with part of their vehicles encroaching on the through lanes of the major road. The analysis of the field data examined the relationship between the median width and the observed frequency of undesirable driving behavior at the intersections.

A statistical analysis was also conducted using a data base of accident, geometric, and traffic volume data for intersections on the California state highway system. This analysis was to determine the relationship of median width to accident frequency at the intersections while considering the effects of traffic volume and other geometric features of the intersection. The statistical analysis used the techniques of Poisson regression and log-normal regression.

The field observational studies and the accident analysis provided similar findings on the operational and safety effects of the median width at intersections. At rural, unsignalized intersections, accidents and undesirable driving behavior decrease as the median width increases. In contrast, at suburban, signalized and unsignalized intersections, accidents and undesirable driving behavior increase as the median width increases. Thus, at rural, unsignalized intersections, wider medians are generally preferable to narrower medians, unless signalization or suburban development are anticipated at a particular intersection. The median at a suburban intersection generally should not be wider than necessary

to accommodate the appropriate median left-turn treatment needed to serve current and anticipated traffic volumes.

The operational effects of median width at signalized intersections were further examined by using existing traffic simulation models. It was found that at a divided highway intersection at which all approaches are controlled by a single signal, vehicle delay increases (and thus, the level of service decreases) as the median width increases. Intersections with median widths of more than 31 m (100 ft) may require separate signals on the two roadways of the divided highway. That signal configuration, which is equivalent to the signal configuration of a diamond interchange, often results in substantially greater vehicle delay than a single signal. Those operational findings reconfirm the finding of the accident analysis that median widths at signalized intersections should be kept to the minimum necessary to accommodate the current (or anticipated) left-turn treatments.

CHAPTER 1

INTRODUCTION AND RESEARCH APPROACH

Multilane, divided cross sections are frequently used by highway agencies for major, nonfreeway facilities in rural and suburban areas (*1,2*). The multilane cross section enables the highway to operate between intersections with a capacity (under ideal conditions) approaching that of a freeway (*3*). The median separates the vehicles traveling in opposite directions and reduces accident rates below the levels found on undivided highways.

At-grade intersections are a major source of traffic operational and safety problems on multilane, divided highways. Turning volumes are generally larger at intersections than at driveways and midblock median openings, and accidents tend to cluster where the turning volumes are largest.

The 1994 American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (*1*), also known as the "Green Book," establishes geometric design policies for most highway features, including intersections. The AASHTO Green Book identifies the width of medians at intersections on highways with partial or no access control as critical to their operation and safety.

Figure 1 illustrates typical, four-leg, at-grade intersections on a four-lane, divided highway without and with left-turn lanes. Figure 2 illustrates a design with a wide median, where the junctions of the crossroad with each roadway of the divided highway may operate, in effect, as separate intersections.

Research on the safety effects of median width has focused on the rate of cross-median accidents between intersections (i.e., accidents in which one or more vehicles traverse the median and enter the opposing lanes), but only limited work has been done on the influence of the median width on the operation of at-grade intersections. Thus, in many cases, the median widths of multilane nonfreeway facilities may be selected to meet the safety needs of the highway links between intersections without focusing specifically on the role of the median width in intersection design and operations.

Chapter VII of the AASHTO Green Book (*1*) discusses the selection of the median width for rural arterials. Median widths generally range from 1.2 to 24 m (4 to 80 ft) or more. The Green Book states that on highways without at-grade intersections, the median may be as narrow as 1.2 to 1.8 m (4 to 6 ft) under very restricted conditions, but that a median width of 20 m (60 ft) or more should be provided wherever feasible. However, the Green Book goes on to state that special concerns exist in cases where at-grade intersections are provided.

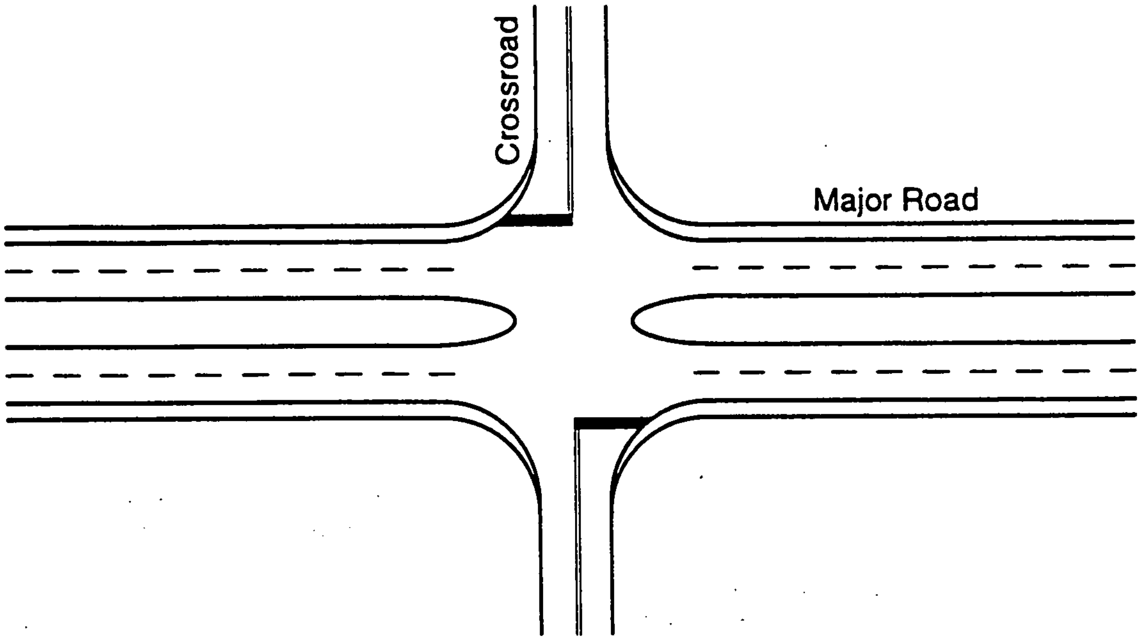
The Green Book suggests that, while median widths as narrow as 1.2 to 1.8 m (4 to 6 ft) may be required at intersections under very restricted conditions, such narrow medians are not desirable. Medians 3.6 to 9 m (12 to 30 ft) wide are preferred because they provide protection for left-turning vehicles at intersections. Median widths in the range of 9 to 15 m (30 to 50 ft) also provide protection for left-turning vehicles but do not provide enough storage space for larger vehicles crossing the median. The concern expressed by the Green Book is that a 9- to 15-m (30- to 50-ft) median width may tempt drivers of vehicles longer than the median is wide, such as trucks and buses, to cross the divided roadways; however, if such longer vehicles are forced to stop in the median, they may extend into the through lanes and create operational and safety problems. The Green Book states that even with these potential problems, intersections on divided highways with median widths in the 9- to 15-m (30- to 50-ft) range generally operate well.

Concerns are also expressed in the Green Book about intersections with median widths in the 15- to 24-m (50- to 80-ft) range. Such intersections provide enough storage area for most large vehicles (or for several passenger cars). However, some intersections of this type have apparently developed operational and safety problems because drivers have become confused about the correct path to follow on the median roadway. The Green Book notes that medians wide enough to ensure that the intersections of the crossroad with each of the divided roadways operate independently generally have worked quite well, but the Green Book also suggests that research may prove that wider medians are not desirable for some kinds of facilities with at-grade intersections. The Green Book emphasizes the potential for confusion created by wider medians on suburban arterials.

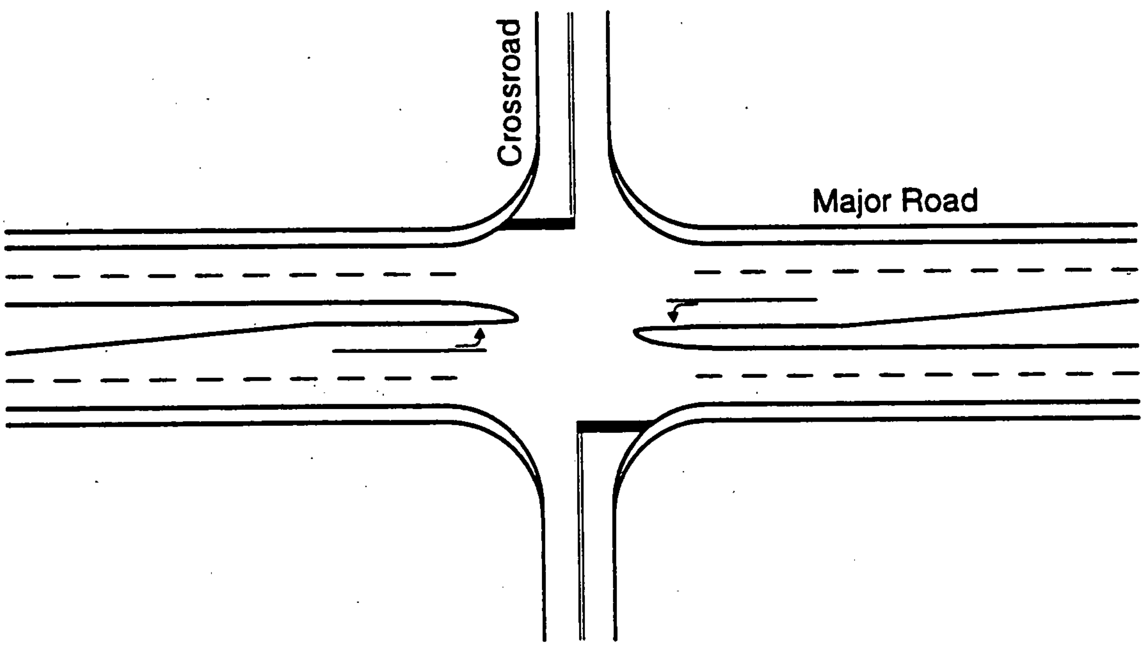
As explained above, the width of the median has obvious implications for how a divided highway intersection will operate for specific traffic volume levels and turning movement patterns; however, driver expectancy and other human factors also affect the safe operation of such intersections. Using a consistent geometric design and traffic control scheme for divided highway intersections that does not change markedly from site to site (especially along the same highway) can be effective in developing safe operations. However, introducing unusual designs at a few locations may violate driver expectancy and lead to safety problems. For example, if a median is so wide that approaching drivers cannot see both intersections at the same time, they may become confused about the correct path through the intersection. That can lead to drivers running through Stop signs that they did not expect or turning the wrong way into a one-way roadway.

In addition to the key geometric variable discussed above—median width—other geometric variables affect the operational and safety performance of a divided highway intersection and should be explored. The most important of these geometric variables are as follows:

- Roadway widths
- Shoulder widths



(a) Without Left-Turn Lanes



(b) With Left-Turn Lanes

Figure 1. Typical divided highway intersections.

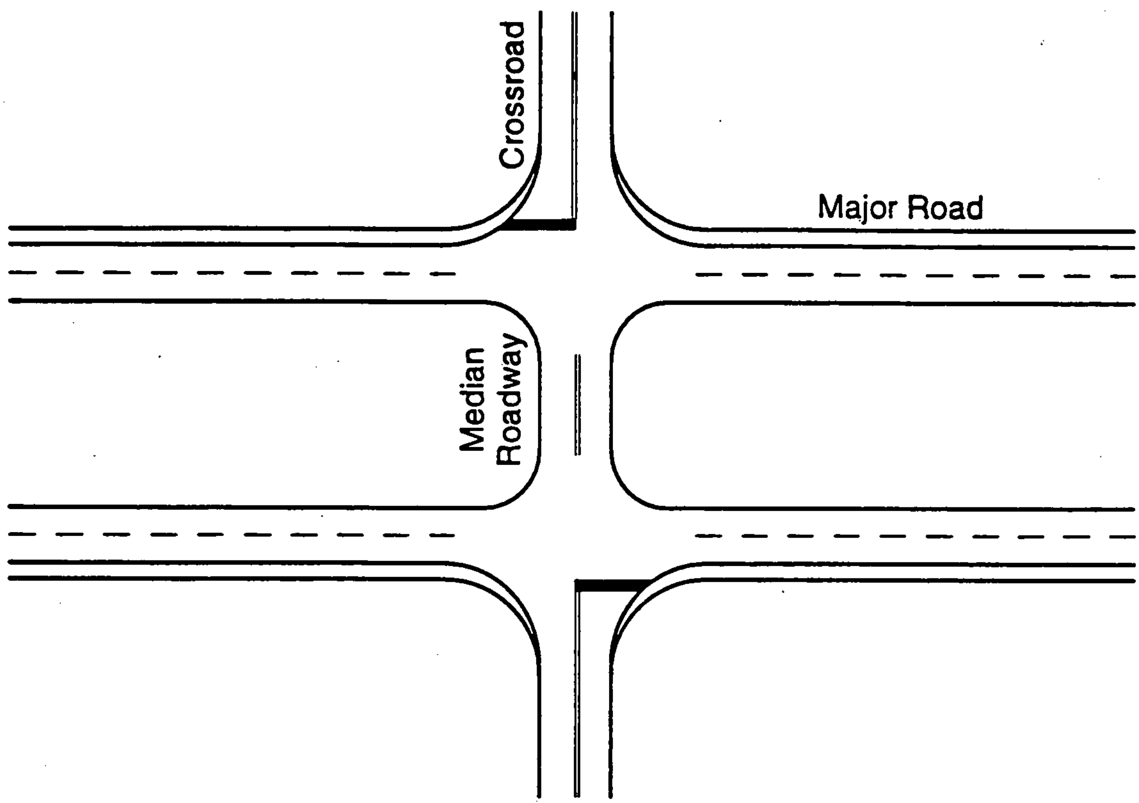


Figure 2. Typical intersection on a divided highway with a wide median.

- Number of lanes
- Left-turn lanes
- Stopping sight distance (SSD)
- Intersection sight distance (ISD)
- Approach curvature
- Approach grade

Understanding the effects of these variables is important for the design of each intersection approach and, most especially, for the median roadway.

The effect of the traffic control devices used at divided highway intersections is also a key consideration. Most rural divided highway intersections have two-way stop control, with Stop signs on the crossroad approaches. However, if the median is wide enough, there may be stop or yield control for the intersection with the major road at each end of the section of roadway within the median. In addition, some rural intersections may operate with four-way stop control, with two-way or four-way stop control supplemented by flashing beacons, or with traffic signals. Furthermore, the use of four-way stop control, flashers, or signals is even more likely in suburban areas than in rural areas. The type of traffic control has a strong influence on the operation of the intersection and, thus, on the operational and safety effects of median width and other geometric elements.

Traffic volumes, traffic characteristics, and vehicle characteristics are also important considerations in intersection design. Key factors include approach volumes, turning volumes, approach speeds, vehicle mix (particularly percentage of trucks and distribution of truck types), vehicle turning paths, and vehicle length.

The current guidance on selecting median widths provided by the Green Book, as related to intersection operations, is general. Because very narrow and very wide medians may lead to operational and safety problems at intersections, highway agencies need more specific guidance concerning the operating experience, advantages, and disadvantages for the complete range of median widths, as well as other geometric considerations in the design of divided highway intersections; this report provides such guidance.

RESEARCH PROBLEM STATEMENT

The NCHRP research problem statement for this research is as follows:

> Operational design of median widths and geometric configurations at intersections to meet the needs of rural and suburban traffic continues to be a concern. As noted in AASHTO's *A Policy on Geometric Design of Highways and Streets*, the width of medians at intersections on highways with partial or no access control is critical to their operation and safety.
>
> Median-width research efforts have, for the most part, addressed freeway operations only. These efforts have provided a significant amount of information on cross-section design and optimum width. However, little or no research has been directed toward developing guidelines for median widths at intersections with partial or no access control.
>
> Median width on these facilities may pose operational problems in the vicinity of intersections for (1) left-turning traffic from the main roadway and (2) crossing or left-turning traffic from cross-

roads. These problems may be created or compounded by other factors, such as the expanse of pavement area, inadequate storage for turning or crossing vehicles, restricted sight distance at the intersection approaches, and violations of driver expectations for traffic movements (for example, drivers tend to become confused about intended operational characteristics of the multiple intersections encountered).

Currently, the focus of many transportation agencies is on the construction or reconstruction of multilane facilities having partial or no access control. Because current design policy does not adequately address median widths or intersection treatments on these types of facilities, guidance is urgently needed.

RESEARCH OBJECTIVES AND SCOPE

The objectives of the research were to develop and recommend median-width parameters and design criteria for intersections on rural and suburban, divided highways with partial or no control of access. Guidelines will be developed, for new or reconstructed facilities, that consider the following factors: safety, traffic operations, traffic volumes, type of traffic control, design speed, traffic characteristics, and design consistency and driver expectancy. Other issues that may be considered include intersection configuration and intersection spacing.

The recommended guidelines have been developed in a form suitable for adoption by AASHTO or individual highway agencies.

Throughout this report the term "divided highway" is used to refer to a multilane, nonfreeway facility with a median separating the through lanes in opposite directions of travel. Divided highways typically have at-grade intersections where median openings are provided to allow vehicles to turn onto and off of the divided highway. Some divided highways are expressways on which direct driveway access between at-grade intersections is restricted; other divided highways may have no control of access between intersections.

The primary intent of the research has been to provide design criteria and guidelines for selecting the median width at intersections on new divided highways that either are being constructed on a new alignment or reconstructed on an existing two-lane highway. The research has also provided insight into effective methods of alleviating operational and safety problems at existing divided highway intersections.

Although very few divided highways are being built on new alignments, many state highway agencies are upgrading the higher-volume portions of their rural two-lane highway system to four lanes. Such projects involve choices of median width and other intersection design elements that have been examined explicitly in the proposed study.

The research has addressed intersections on divided highways in both rural and suburban areas. There were two primary goals for the research. The first goal was to develop rational criteria for defining the appropriate median width and other geometric elements for divided highway intersections in rural areas. The second goal was to develop guidelines for handling the special problems that may develop at intersections at which rural divided highways enter suburban areas. The additional development and traffic volumes present in suburban areas may result in safety problems, installation of traffic signals, pedestrian demands, and many other concerns that are not typical of the rural environment.

The following criteria were used to define suburban divided highways in this research:

- Divided highway traffic volume of more than 7,000 veh/day
- Speeds between 56 to 80 km/h (35 to 50 mph)
- Spacing of at least ¼ mi between signalized intersections
- Direct driveway access from abutting properties
- No curb parking
- Location in or near a populated area

Divided highways outside of populated areas with volumes lower than 7,000 veh/day or speeds higher than 50 mph would generally be defined as rural, although some 88-km/h (55-mph) sites on developed arterials have been classified as suburban in this study. Divided highways with speeds below 56 km/h (35 mph), with spacings between signals of less than ¼ mi or with curb parking would be defined as urban and were outside the scope of this research.

Most existing design policies and guidelines address median widths on divided highways ranging from 1.2 to 15 m (4 to 80 ft). However, particular emphasis in this research was placed on the traffic operational and safety performance intersections with medians wider than 24 m (80 ft). The maximum divided highway median width considered in the study was 92 m (300 ft).

The research focuses on divided highways with raised or depressed (e.g., depressed landscape) medians. Flush medians are also used extensively on arterials, particularly in urban and suburban areas. However, flush medians (e.g., flush-paved) are generally fewer than 6 m (20 ft) wide and have median-width requirements that are much better defined than for raised and depressed medians. Continuous two-way, left-turn lanes (TWLTLs) are considered to be flush medians.

Two key terms used through this report are "median roadway" and "median area." The median roadway is defined as the paved area in the center of the divided highway at an intersection defined by the median width and the median opening length, as shown in Figure 3. Much of the research focused on the traffic operational and safety problems that can occur on the median roadway. The median area is defined as the median roadway plus the major-road left-turn lanes (if any) at the intersection. The median area is also illustrated in Figure 3.

The median width is defined in all cases as the total width between the edges of the through lanes, including the left shoulder and the left-turn lanes (if any). The median opening length is the distance parallel to the through lanes of the divided highway between the noses or ends of the median on either side of the intersection.

RESEARCH APPROACH

The general approach to this research was to investigate the effect of the dimensions of the median roadway on traffic accidents and traffic operational problems at divided highway intersections. The research included the following six major data collection and analysis activities:

- A review of current geometric design policies concerning divided highway intersections and a current practices survey of state highway agencies

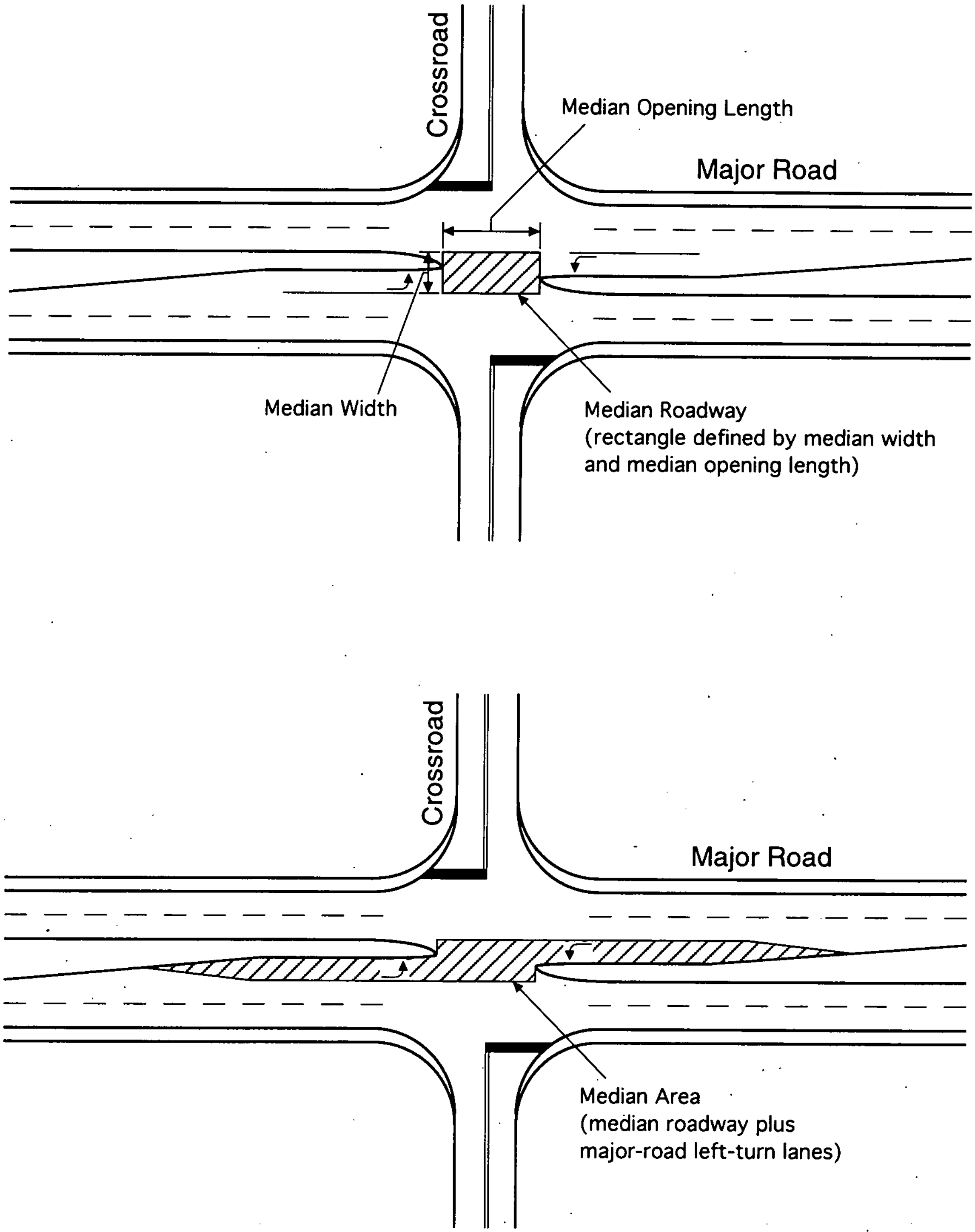


Figure 3. Definition of median roadway and median area.

- A review of literature to document current knowledge of divided highway intersections
- A field observational study of traffic operations at 40 selected divided highway intersections
- An analysis of the traffic accident history of the field observational study sites
- A traffic accident analysis of divided highway intersections using a statewide data base of accident, geometric traffic control, and traffic volume data pertaining to California
- A traffic operational analysis of signalized intersections using existing simulation models

The findings of these analyses were used to develop guidelines

for median widths and other design features at divided highway intersections.

ORGANIZATION OF THIS REPORT

The remainder of this report, following this introduction, is organized into three chapters and seven appendixes. Chapter 2 summarizes the findings of the study, including the findings of the analyses described above. Chapter 3 discusses the interpretation, appraisal, and application of the research findings, with emphasis on their design implications and the resulting design guidelines. Chapter 4 summarizes the conclusions of the study and presents recommendations for future research.

The appendixes present the results of the research in greater detail than the main text. The results of a survey of state and local highway agencies concerning their design practices and operational experience with divided highway intersections are presented in Appendix A. The results of the analysis of field observational study data for divided highway intersections are presented in Appendix B. Appendix C presents an accident analysis of the field observational study sites. Analyses of a California statewide accident data base are presented in Appendix D. Appendix E presents the results of a traffic operational analysis of the effect of median width at signalized intersections. The sight distance implications of offsetting opposing left-turn lanes are addressed in Appendix F. Appendix G presents the recommended changes in design policies, for divided highway intersections, that resulted from the research.

CHAPTER 2

FINDINGS

This chapter presents the findings of the research and explains the data collection and analysis that led to these findings. Details of the data collection and analysis efforts conducted for the research are in appendixes to this document. The recommended revisions to the Green Book are repeated in Appendix G.

The issues addressed in this chapter include data collection and analysis overview, current design policies and practices of highway agencies, safety characteristics of divided highways and divided highway intersections, traffic safety and operational effects of median width, traffic control at divided highway intersections, truck considerations, left-turn treatments, intersection sight distance (ISD), human factors/driver perception considerations, and driver expectancy issues.

DATA COLLECTION AND ANALYSIS OVERVIEW

The Research Approach section of Chapter 1 identified the six major data collection and analysis activities in the research. The following discussion provides an overview of each of these data collection and analysis efforts. The findings of those analyses are presented later in this chapter.

Design Policy and Practice Review

A review of current geometric design policies and practices for divided highway intersections was conducted as part of the research. This effort included a review of the AASHTO Green Book (*1*), other related AASHTO policies, and state and local design policies concerning divided highway intersections.

A mail survey was conducted to document the current design practices of state and local highway agencies. Responses to this survey were received from 43 of the 50 state highway agencies and 19 of 51 local highway agencies, corresponding to response rates of 86 percent and 37 percent for state and local agencies, respectively. The survey questionnaire and the survey results are presented in full in Appendix A and are summarized below.

Literature Review

A review of literature presenting current knowledge related to divided highway intersections was conducted. The findings of this literature review appear throughout this chapter as specific topics are discussed.

Field Observational Studies

Field observational studies were conducted at 40 selected intersections on divided highways. The field sites included 20 rural, four-leg, unsignalized intersections; 8 suburban, four-leg, unsignalized intersections; 6 suburban, four-leg, signalized intersections; and 6 intersections with special features. The intersections with special features included T-intersections, intersections with tapered and parallel offset left-turn lanes, and intersections with median acceleration lanes. The intersections were located in 10 states, including states in all major regions.

Field studies were conducted at each of the 40 intersections. The field studies included video recording of traffic operations at each intersection for 4 to 6 hr. Night studies of 2 hr each were also performed at three intersections. The video data were reduced in the office to determine the turning movement volumes at the intersections; the frequency of undesirable driving behavior (such as side-by-side queuing on the median roadway, angle stopping on the median roadway, and encroaching by stopped vehicles on the through lanes of the divided highway); the frequency of traffic conflicts between through and turning vehicles; and driver compliance with traffic control devices, particularly Stop and Yield signs on the median roadway. These data were analyzed to determine whether a relationship existed between observed traffic operational problems, including undesirable driving behavior, and the median width or median opening length at the intersection.

Accident History of Field Study Intersections

Traffic accident data were obtained from the participating state highway agencies for each of the 40 field study intersections. These data were in the form of either printouts summarizing the characteristics of each accident or hard copy police accident reports. One state highway agency also provided computer-generated collision diagrams of the accident experience at the study sites. The accident data generally covered a period of 3 years for each site, although up to 5 years of accident data were available for a few sites. On the average, 3.4 years of accident data per site were available. During these periods, there were 642 traffic accidents at the 40 intersections.

These data were analyzed to determine whether a relationship existed between the median width or median opening length at the intersections and their accident experience. Collision diagrams were prepared and the dominant accident pattern(s) were identified at each intersection; these accident patterns were reviewed to determine whether they were related in any way to the median width, the median opening length, or the design of

the median roadway. Analyses were also conducted to determine whether trucks were overrepresented in accidents at divided highway intersections.

Statewide Traffic Accident Analysis

A traffic accident analysis was conducted with a statewide data base of accident, geometric, and traffic control data for state highways in California. Data were extracted from this data base and analyzed for rural and urban/suburban, three-leg and four-leg, unsignalized intersections and for urban/suburban, four-leg, signalized intersections on divided highways. These analyses were intended to determine whether a statistically significant relationship existed between median width and accident experience at these types of intersections.

Traffic Operational Modeling of Signalized Intersections

An analysis was conducted of the effect of median width on traffic operations at signalized intersections. As the median at a signalized intersection becomes wider, more clearance or "lost" time is required in the signal cycle for vehicles to clear the intersection at the end of each green phase for crossroad and major-road left-turn traffic. Thus, for a given traffic volume level and turning movement pattern, the signal operations will be less efficient as the median becomes wider. Signalized intersections with median widths of 31 m (100 ft) or more may require separate signals on each roadway of the divided highway. This configuration, which is equivalent to the type of signalization provided at a diamond interchange, is less efficient than an intersection with a single signal. However, these relationships have never been formally quantified.

Simulation modeling was conducted using the PASSER II-90, PASSER III, and Texas models (*4*, *5*, *6*, *7*) to quantify the effect of median width on traffic delay at signalized intersections and the differences in delay between the single and diamond signal configurations. Two traffic volume levels were postulated: a moderate-volume level that corresponds roughly to Level of Service B and a high-volume level that corresponds to traffic operations on the boundary between Levels of Service C and D. For each volume level, a baseline set of turning movement patterns (i.e., percentages of the total approach volume making each turning movement) and four variations of turning movement patterns for that baseline were postulated. For each combination of traffic volume level and turning-movement pattern, an optimal signal timing was determined and then that timing was used in simulation modeling to estimate the total delay that would be experienced by traffic at several levels of median width. The results of this modeling effort represent quantitative estimates of the effect of median width and signal configuration on the efficiency of traffic operations at signalized intersections on divided highways.

CURRENT DESIGN POLICIES AND PRACTICES OF HIGHWAY AGENCIES

This section presents the current design policies and practices of highway agencies related to highway medians, median width, and median intersection design. Design policies at the national level are based on the AASHTO Green Book (*1*). The presentation of state and local agency design policies is based on responses to the survey of highway agencies that is reported in Appendix B. Most highway agency design policies are based on the AASHTO Green Book, although many agencies have their own design manuals and have adapted the AASHTO policies to their own needs.

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

Functions and Types of Medians

A median is defined on page 367 of the AASHTO Green Book as ". . .the portion of the highway separating the traveled way for traffic in opposing directions." The Green Book states that "A median is highly desirable on arterials carrying four or more lanes."

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

- Minimize interference of opposing traffic
- Provide a recovery area for out-of-control vehicles
- Provide a stopping area in case of emergencies
- Provide open green space
- Minimize headlight glare from opposing vehicles
- Provide width for future lanes
- Provide space for speed-change lanes and storage areas for left- and U-turn vehicles
- Restrict left turns except where median openings are provided

There are three major types of medians: raised, depressed, and flush. Flush medians include painted medians and continuous TWLTLs. The divided highways of interest in this study typically have either raised or depressed medians. However, some flush medians have some of the same intersection design considerations as raised or depressed medians and some divided highways may incorporate limited sections with flush medians.

Median Width

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

Median Width Between Intersections

AASHTO Policy: The median width between intersections is defined as the distance between the edges of the through lanes

in opposing directions, including the width of the left shoulders, if any.

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

Most divided highways have median widths in the range of 1.2 to 24 m (4 to 80 ft); however, median widths wider than 24 m (80 ft) have been used. AASHTO policies impose no limit on maximum median width.

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

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

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

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

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

Whenever possible, medians should be designed with sufficient width to avoid the need for a median barrier. Figure 4 shows the median barrier warrants applicable to high-speed freeways and divided highways with partial control of access (expressways) that are presented in the AASHTO *Roadside Design Guide* (*4*). As shown in the figure, most medians less than 9 m (30 ft) wide on highways with average daily traffic (ADT) of more than 20,000 veh/day warrant a median barrier. The figure shows that median barriers are optional for medians 9 to 15 m (30 to 50 ft) wide on higher-volume highways and for some medians less than 6 m (20 ft) wide on highways with ADT of less than 20,000 veh/day. Where median barriers are optional, they should be used only if a history of cross-median accidents exists. Median barriers are not appropriate for flat medians more than 50 ft wide. However, if steep slopes or objects in the median cannot be removed, roadside barriers may be warranted for medians of any width; the *Roadside Design Guide* provides procedures to address the cost-effectiveness of barrier needs in such situations. Median barriers are less desirable on divided highways without full control of access than on freeways because terminating the barrier at intersections may be difficult and because the barrier may restrict ISD.

In summary, the Green Book does not prescribe particular median widths for particular types of highway facilities. Instead, it summarizes the advantages and disadvantages of particular median widths and permits designers to make choices case by case.

Highway Agency Policies: The highway agency survey presented in Appendix A found a range of highway agency views on the appropriate median width for divided highways. State highway agencies were asked to assess the minimum, desirable, and maximum median widths for rural and urban nonfreeways. These assessments may reflect median width requirements between intersections and the effects on intersection operations. Table 1 summarizes the survey results on median width requirements.

The minimum median widths for rural nonfreeways reported by state highway agencies varied greatly, from as little as 0.9 m (3 ft) to as much as 20 m (64 ft). Approximately 42 percent of the responses recommended minimum median widths of greater than 9 m (30 ft). Desirable median widths for rural divided highways ranged from 5 to 26 m (18 to 84 ft). Approximately 62 percent of the responses indicated a desirable median width of more than 15 m (50 ft). Many state highway agencies did not indicate a maximum median width, implying that the median should be as wide as possible; those agencies that did respond indicated maximum median widths ranging from 8 to 92 m (25 to 300 ft).

Another recent survey of state highway agencies concerning median widths on rural divided highways without full control of access (*9*) found similar results to the survey conducted in the present research. Table 2 summarizes the range of minimum, desirable, and maximum median widths found in the survey. Note that the range of desirable and maximum median widths found in the survey was not as broad as the range found in the current study.

For urban and suburban nonfreeways, the minimum median widths indicated by state highway agencies ranged from 1.2 to 9 m (4 to 30 ft). Approximately 56 percent of respondents indi-

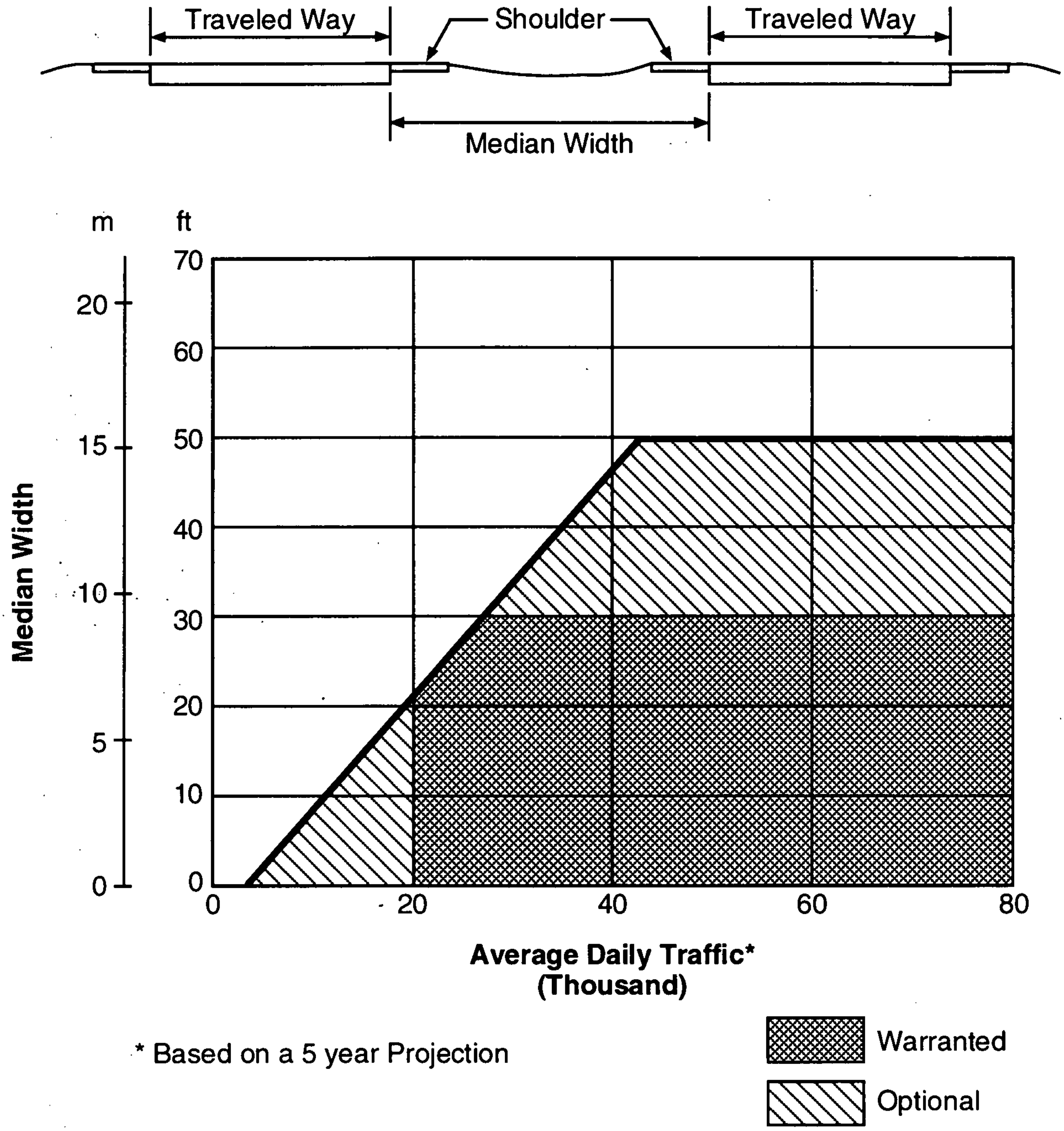


Figure 4. Median barrier warrants for freeways and expressways (4).

TABLE 1. Summary of highway agency survey results on minimum, maximum, and desirable widths for divided highway medians

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

TABLE 2. Summary of results from a recent survey on rural divided highway median widths (*9*)

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

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

Median Width at Intersections

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

AASHTO Policy: The AASHTO Green Book policies on median width at intersections are presented in the Green Book chapters that deal with specific functional classes of highway: local roads and streets, urban collector roads and streets, and rural and urban arterials.

The most extensive discussion of the attributes of different median widths is found in the section on rural arterials on pages 498 and 499 of the 1994 Green Book. The following material from that discussion summarizes what is known about the advantages and disadvantages of different median widths on divided highways:

> When intersections are to be provided, special concern must be given to the width of the median. While medians as narrow as 1.2 to 1.8 m may be required under very restricted conditions, medians 3.6 to 9 m wide provide protection for left turning vehicles at intersections.
>
> Median widths from 9 to 15 m should be carefully considered from an operational standpoint at intersections. These widths do not provide median storage space for larger vehicles crossing the median. Also, these widths may encourage the driver to attempt the crossings independently leaving a portion of the vehicle unprotected from through traffic. These widths, even with these problems, normally operate quite well and apparently are within the realm of normal operational expectations of the driver. Widths in the range of 15 to 24 m have developed accident problems in some areas as the drivers apparently tend to become confused about the intended operational characteristics of the multiple intersections encountered. Medians wide enough to assure the driver that the intersection with the two sets of lanes operate separately have worked quite well. Research may prove that wider medians are not desirable for some facilities with at-grade intersections (*1*).

While the preceding discussion identifies the potential advantages and the possible operational problems of different median widths, it is not very specific. The designer is left without much guidance in the use of median widths in the ranges of 9 to 15 m (30 to 50 ft) and 15 to 24 m (50 to 80 ft) because the Green Book implies that medians in these width ranges operate well in most cases but may develop operational problems in some cases. An important objective of the present research is to obtain better information about the circumstances under which operational problems can occur, the causes of such operational problems, and how they can be avoided or eliminated.

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

> Medians are a desirable feature of arterial streets and should be provided where space permits. . . . Where right-of-way is limited, it is frequently necessary to decide how best to allocate the available space between border areas, traffic lanes, and medians. On the less important arterials the decision is often resolved in favor of no median at all. A median only 1.2 m wide is better than none; however, each additional foot provides an added increment of safety and improved operation. At intersections where left-turns are made, a left-turn lane is always desirable from a capacity and safety standpoint. The median width to accommodate left-turning movements should desirably be at least 3.6 m. Desirably, the median should be at least 5.4 m wide for a 3.6 m median lane and a 1.8 ft medial separator. At restricted locations, a 3.0 m lane with a 0.6 m medial separator may be used (*1*).

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

The Green Book notes on page 519 that, for urban arterials, "Experience indicates that drivers prefer medians that are either obviously narrow or those that provide an adequate refuge area to allow independent roadway crossing operation." This statement is made from the point of view of the driver on a minor-road approach to a divided intersection who intends to cross or turn left onto the divided highway. Drivers making such maneuvers would prefer to have a median that is at least wide enough to store their vehicle (i.e., at least 8 m [25 ft] wide for a passenger car design vehicle). If a median of that width cannot be provided, the median width might as well be as narrow as possible because, from the point of view of the driver crossing or turning onto the divided highway, wider medians just mean additional travel time and distance (and longer required gaps in traffic) without any benefit from a safe waiting area in the median. On the other hand, from the point of view of the driver turning left off the divided highway, medians wide enough to include separate left-turn lanes at intersections are desirable.

Highway Agency Policies: Approximately 76 percent of state highway agencies indicated that they consider intersection operations in selecting the median width for a divided highway. Approximately 50 percent of the responding highway agencies indicated that storage needs in the median area have influenced either their median width policy or their choice of median width for particular projects.

Several highway agencies reported that they have selected a large school bus as the design vehicle for median width on rural divided highways. Typically, such agencies use medians with a minimum width of 15 m (50 ft) to store the largest school bus safely, which is 12 m (39.5 ft) long and carries 84 passengers. Other highway agencies stated that they consider the expected queue lengths of left-turning vehicles in selecting the median width.

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

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

On the other hand, 19 state highway agencies, or 45 percent of the agencies that responded to the question, indicated that they have encountered traffic operational or safety problems at intersections with median widths that they consider to be too narrow. Most of these problems were related to turning and crossing maneuvers by trucks and buses.

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

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

Only six state highway agencies, or 15 percent of the respondents, indicated that they have median width policies that differentiate between the median widths used at signalized and unsignalized intersections. This is a concern because operating experience has shown that intersections with wider medians are difficult to signalize effectively.

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

Left-Turn Lanes

The following discussion addresses lanes provided for left turns from a divided highway onto a crossroad.

AASHTO Policy

AASHTO policy on left-turn treatments for at-grade intersections is presented on pages 778 through 787 of the 1994 Green Book (*1*). The Green Book states that auxiliary lanes, such as left-turn lanes at intersections or median openings, should be at least 3 m (10 ft) wide and, preferably, as wide as the through lanes. Figure 5, which is Green Book Figure IX-74, illustrates a typical median left-turn lane. The Green Book encourages the use of median left-turn lanes because accident potential, inconvenience, and considerable loss in efficiency are evident at intersections on divided highways where median left-turn lanes are not provided.

Where curbing is to be provided adjacent to the roadway, an appropriate curb offset should be provided. The Green Book states on page 348 that "For low speed street conditions, mountable curbs may be placed at the edge of a through lane, although it is preferable that the curbs be offset 0.3 to 0.6 m. . . .Barrier curbs introduced intermittently along streets should be offset. . . .at least 0.3 m, and preferably 0.6 m."

The length of auxiliary lanes consists of three components: (1) deceleration length, (2) storage length, and (3) entering taper. Ideally, the total length of the auxiliary lane should be the sum of these three components. The Green Book notes, however, that common practice is to accept a moderate amount of deceleration within the through lanes and to consider the taper as part of the deceleration length. The following minimum deceleration lengths are recommended for auxiliary lanes on arterial roads and streets with grades of 2 percent or less:

Design Speed km/h (mph)	Deceleration Length m (ft)
50 (30)	70 (235)
60 (40)	100 (315)
80 (50)	130 (435)

These lengths exclude the length of the taper, which should be approximately 2.4 to 5 m (8 to 15 ft) longitudinally to 0.3 m (1 ft) transversely (i.e., 8:1 to 15:1). Where these deceleration lengths cannot be provided, some deceleration in the through lanes will be required of left-turning vehicles.

At unsignalized intersections, the storage length (exclusive of taper) may be based on the number of left-turn vehicles likely to arrive in an average 2-min period during the peak hour. As a minimum requirement, space for at least two passenger cars should be provided; at locations with more than 10 percent truck traffic, provision should be made to store at least one passenger car and one truck. The 2-min storage period may need to be modified depending on the actual waiting time required to complete a left turn at specific intersections.

At signalized intersections, the required storage length depends on the signal cycle length, the signal phasing arrangements, and the rate of arrival and departure of left-turning vehicles. The storage length should usually be 1.5 to 2 times the average number of vehicles that would store (i.e., arrive on a red signal indication) per cycle. The same minimum storage lengths apply as were discussed above for unsignalized intersections.

The Green Book states on page 783 that "median widths of 6 m (20 ft) or more are desirable at intersections with single left-turn lanes in the median, but widths of 4.8 to 5.4 m (16 to 18 ft) permit reasonably adequate arrangements. Where two median lanes are used, a median width of at least 8.4 m (28 ft) is desirable to permit installation of two 3.6-m (12-ft) lanes and a 1.2-m (4-ft) separator. Although not equal in width to a normal traveled lane, a 3-m (10-ft) lane and a 0.6-m (2-ft) curbed separator (or with traffic buttons, paint lines, or both), separating the median lane from the opposing through lane may be acceptable

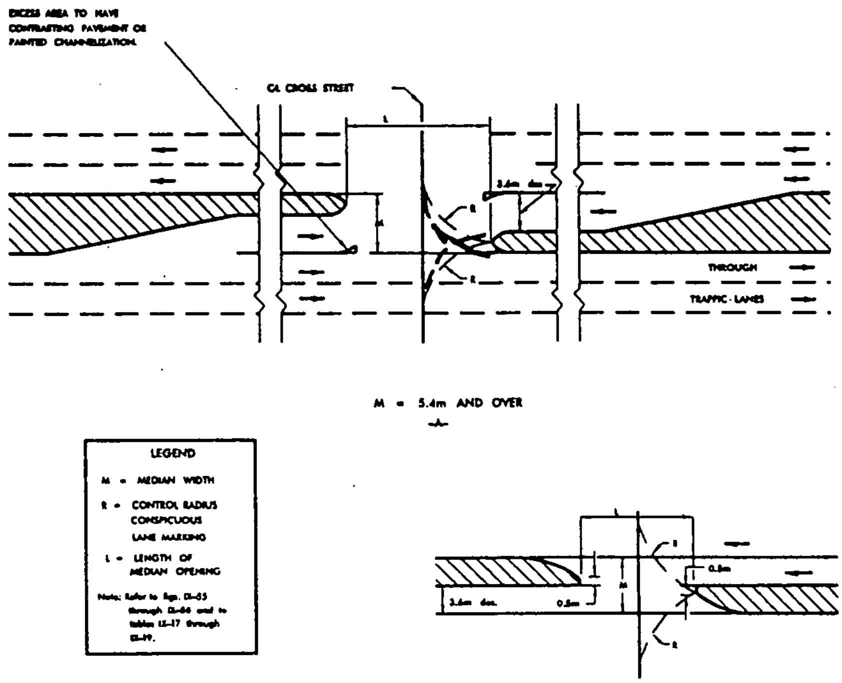


Figure 5. Key dimensions in median left-turn lane design (1).

where speeds are low and the intersection is controlled with traffic signals."

The Green Book on page 787 alludes to the potential for offsetting left-turn lanes and angling the left-turn lanes toward the opposing lanes to improve visibility of opposing traffic, to decrease the possibility of conflict between opposing left-turn vehicles, and (at signalized intersections) to increase the saturation flow rate for left-turn vehicles. As discussed below and in Appendix F, some highway agencies have developed more extensive policies on improving safety and capacity by offsetting left-turn lanes and angling them toward the opposing lanes.

Highway Agency Policies

Conventional Left-Turn Lanes: A key issue in the design of intersections on divided highways is the location of left-turn lanes.

In their responses to the survey questionnaire summarized in Appendix A and in preliminary discussions with the research team, a few state highway agencies indicated that they provide left-turn lanes at all median openings (intersections or driveways) on rural divided highways where a left turn is possible (i.e., everywhere except, in one direction of travel, at T-intersections). In some states, this practice is a formal policy; in other states it is more a consistent procedure.

Most states use guidelines or warrants to determine whether a left-turn lane should be provided at a particular location. Some examples of warrants for left-turn lanes that are in current use and were identified by states responding to the survey questionnaire are presented below. Left-turn lanes are provided at the following locations:

- Where the left-turn design volume exceeds 20 percent of the total directional approach design volume
- Where the left-turn design volume exceeds 100 veh/hr in the peak period

In addition, several state highway agencies use a series of nomographs to determine if left-turn lanes are warranted (*10*). These nomographs—typically based on the work of Harmelink (*11*) in the 1960s—use input parameters of speed, the opposing volume, (V_O), the advancing volume (V_A), the left-turning volume (V_L), and the percentage of left turns in the advancing volume. The nomographs developed by Harmelink are illustrated in Figure 6.

Existing highway agency design guidelines for left-turn lanes are generally similar to those in the AASHTO Green Book. With respect to left-turn storage length, some highway agencies permit minimum designs with space to store only one passenger car, in contrast to the Green Book, which requires storage space for two vehicles. Other highway agencies require sufficient storage length for two passenger cars or one truck. Still, other highway agencies require a minimum of 15 m (50 ft) of storage length, which is approximately equivalent to providing storage space for two passenger cars.

Double Left-Turn Lanes: Double left-turn lanes are typically used only at signalized intersections, although the research team is aware of one location where they have been used at an unsignalized intersection. State highway agencies have reported use of the following guidelines for determining where double left-turn lanes should be provided:

- At locations where there is insufficient space to provide the necessary left-turn storage length in a single turn lane

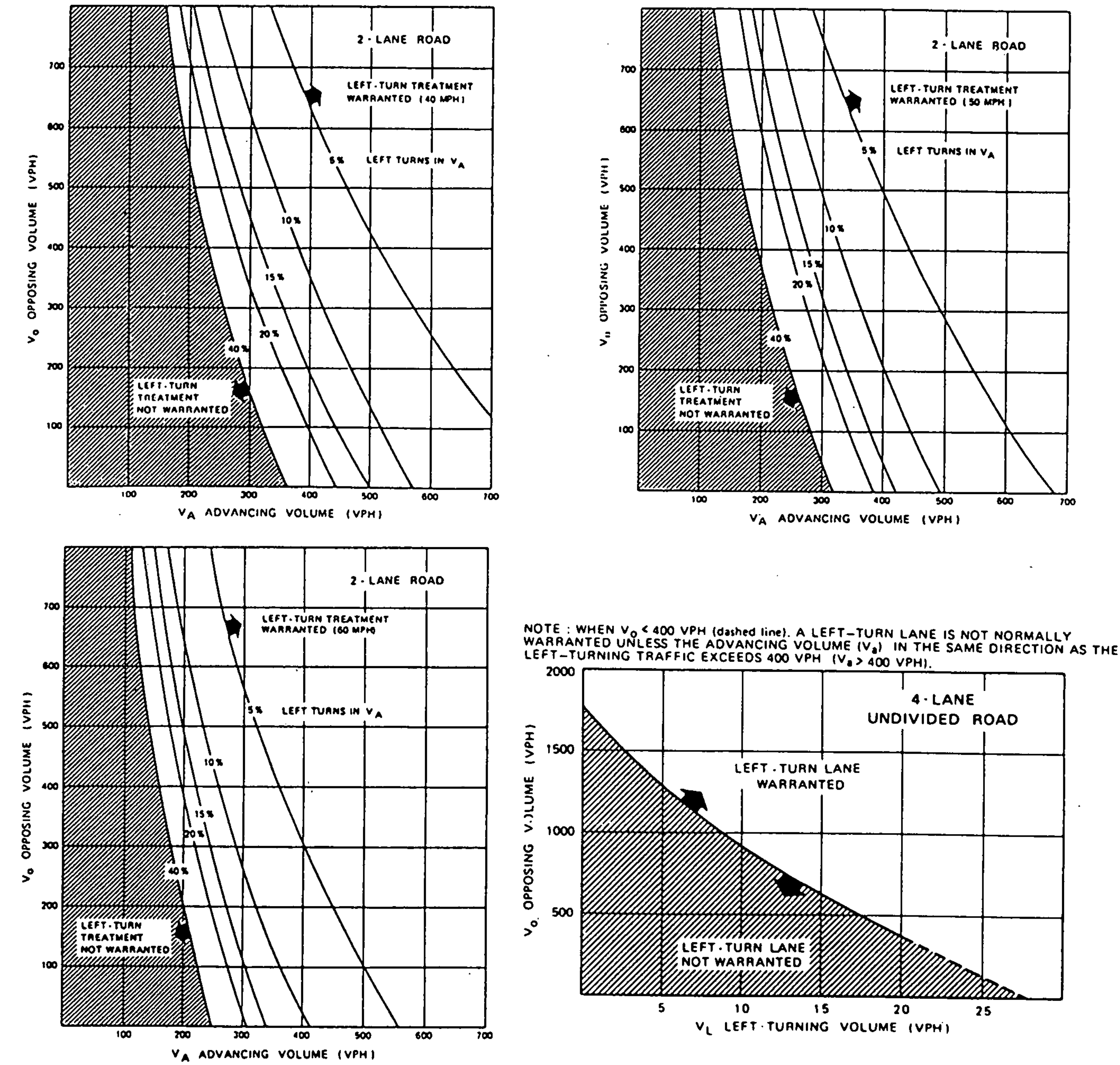


Figure 6. Nomographs for determining volume warrants for provision of left-turn lanes. (11)

- At locations where the storage length needed for a single left-turn lane would be excessive
- At locations where the necessary time for a protected left-turn phase for a single lane becomes unattainable to still meet level-of-service criteria
- At locations where the left-turn volume exceeds 300 veh/hr (or, in the case of a different agency, 330 veh/hr)

Although not yet common, one highway agency has reported that it has begun to provide triple left-turn lanes at high-volume suburban intersections on divided highways.

Offset Left-Turn Lanes: Wider medians generally have positive effects on traffic operations and safety. However, wider medians can create sight obstructions for left-turning vehicles when confronting opposing left-turn vehicles. This type of sight obstruction is illustrated in the two diagrams in Figure 7. The upper portion of the figure illustrates an intersection with a relatively narrow median in which opposing left-turn vehicles block the view of approaching through traffic for a driver in the left-turn lane. The lower portion of the figure shows an intersection with a wider median; this diagram shows that even when a left-turning vehicle advances from the left-turn lane onto the

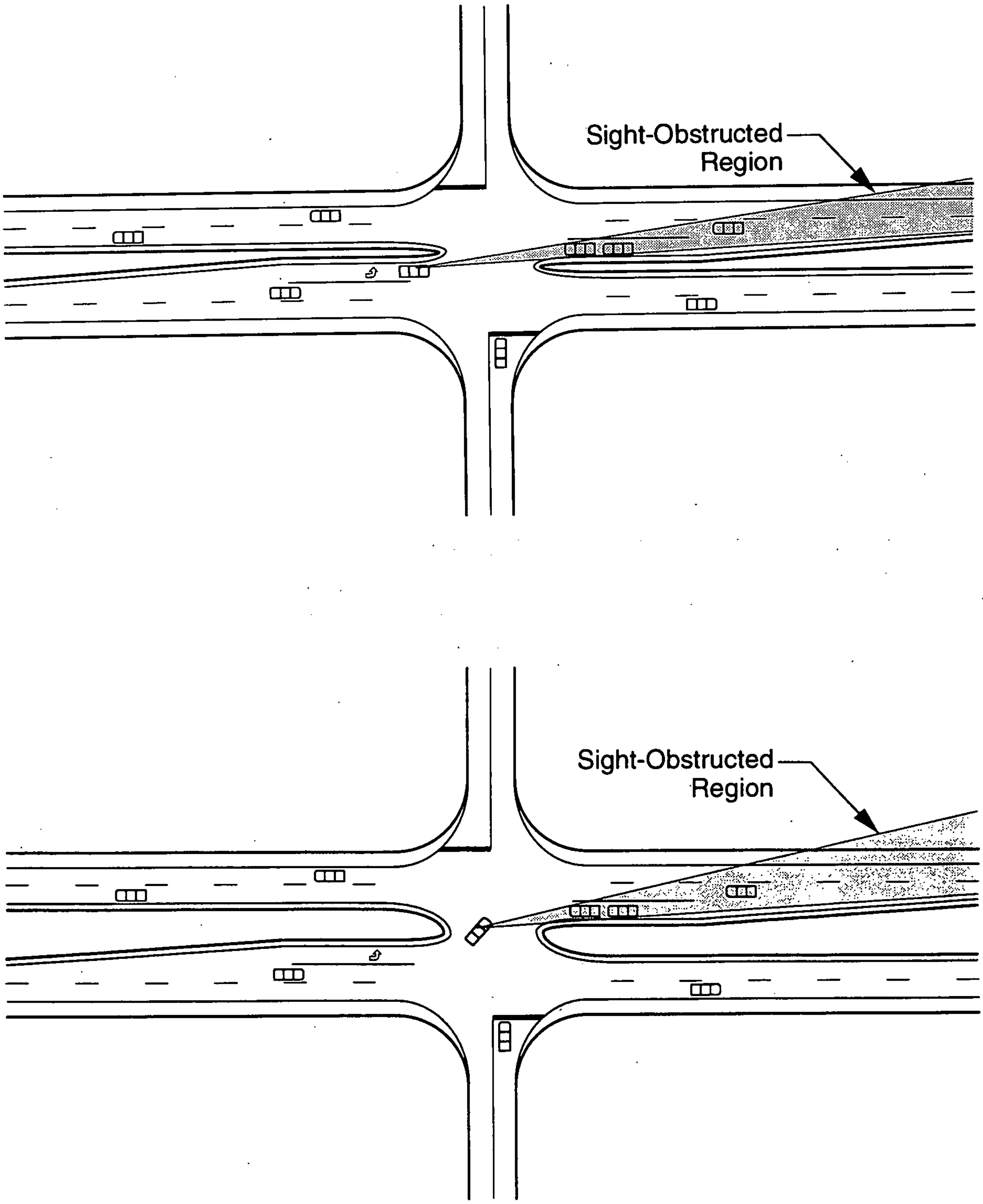


Figure 7. Examples of sight obstructions caused by opposing left-turn vehicles (9).

median roadway, the opposing left-turn vehicles still block the driver's view of approaching through traffic.

The most common solution to this problem is to offset the left-turn lanes (i.e., to move the left-turn lanes laterally within the median) so that the opposing left-turn vehicles no longer block the line of sight of the two drivers. Figure 8 compares conventional left-turn lanes with two alternative configurations: parallel offset and tapered offset left-turn lanes. Offset left-turn lanes are most common at signalized intersections, but highway agencies have begun to use them to minimize sight obstructions at unsignalized intersections as well.

The survey responses summarized in Appendix A indicate

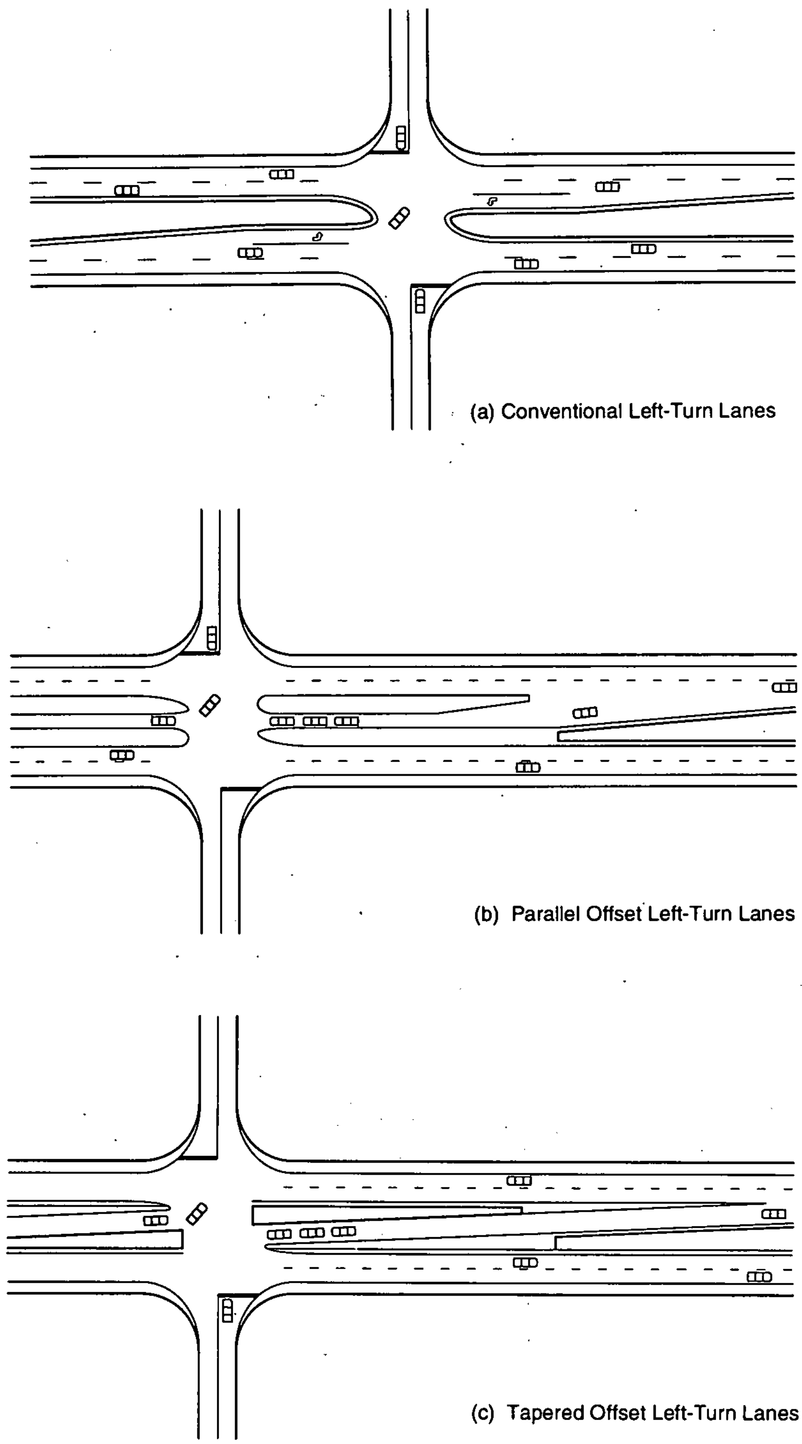


Figure 8. Alternative left-turn treatments for rural and suburban divided highways (9).

that 16 state highway agencies, or 37 percent of those responding, have used offset left-turn lanes. Parallel offset left-turn lanes with 3.6 m (12-ft) widths can be constructed in raised medians with widths as narrow as 7.2 m (24 ft), and can be provided in narrower medians if restricted lane widths or curb offsets are used or a flush median is provided (*9*). Tapered offset left-turn lanes generally also require raised medians 7.2 m (24 ft) or more wide. Appendix F addresses the amount of offset between the opposing left-turn lanes required to minimize the sight distance obstructions caused by opposing vehicles.

On the basis of the information obtained to date, it appears that the Illinois Department of Transportation (IDOT) has the

most extensive experience with offset left-turn lanes. IDOT has adopted a design policy of providing left-turn lanes at all median openings (i.e., both intersections and driveways) where left turns off the highway are possible. Left-turn lanes are provided in both directions of travel on the divided highway at four-leg intersections and in one direction of travel at T-intersections. Tapered offset left-turn lanes are generally provided by IDOT where the median widths are 12 m (40 ft) or more, where the current crossroad ADT (average of both approaches) is 1,500 veh/day or more, and where the current left-turn design hour volume in each direction from the major road is more than 60 veh/hr. At signalized intersections, tapered offset left-turn lanes are used on the major road where only one left-turn lane in each direction of travel is needed for capacity.

Several potential disadvantages of offset left-turn lanes have been cited by highway engineers. These include the following:

- Lack of driver familiarity with the offset left-turn lane design
- Potential confusion for older drivers
- Roadside safety concerns, if barrier curbs are used
- Increased difficulty of making U-turns for both motorists and emergency vehicles
- Difficulty of snow removal and deicing activities on the separate left-turn roadway
- Potential for wrong-way movements by opposing direction vehicles entering the left-turn roadway

IDOT has considered these potential disadvantages and discounted them on the basis of its operating experience. IDOT has found that problems with driver confusion associated with offset left-turn lanes are minimal if proper signing and pavement markings are used (i.e., advance signing and pavement arrows on the entrance to the left-turn lane). No problems have been observed with drivers entering the left-turn roadway in the wrong direction. Although barrier curbs have been used in older designs, roadside safety concerns can be minimized with the use of mountable curbs, and IDOT now uses mountable curbs. Although plowing and deicing of the left-turn roadway will require a separate pass by the plow truck, curbing is often needed for conventional left-turn lanes as well. Finally, on divided highways with two or more lanes in each direction of travel, U-turns by passenger cars (but not always by larger vehicles) can be completed within the width of the opposing lanes (see the figure presented in the subsequent section on U-turn treatments). U-turns by snow plows or emergency vehicles can be made, if necessary, directly from the through lanes onto the median roadway without using the left-turn roadway.

Offset left-turn lanes offer a potential advantage at signalized intersections: the signal operation can be made more efficient by reducing the clearance time at the end of the left-turn phase.

Median Acceleration Lanes

Median acceleration lanes are increasingly used at intersections on high-speed divided highways. However, median acceleration lanes are not appropriate for all divided highway intersections. The AASHTO Green Book states the following on pages 750 and 751:

> Acceleration lanes are not always desirable at stop-controlled intersections where entering drivers can wait for an opportunity to merge without disrupting through traffic. Acceleration lanes are advantageous on roads without stop control and on all high-volume roads even with stop control where openings between vehicles in the peak-hour traffic streams are infrequent and short (*1*).

Median acceleration lanes are generally constructed with a parallel design with a taper length of approximately 92 m (300 ft). Median acceleration lanes can be used both at T-intersections and at four-leg intersections. The use of a median acceleration lane at a four-leg intersection probably changes the turning paths and conflict patterns of opposing vehicles within the median roadway, but the extent of this effect is unknown. Figure 9 illustrates a typical four-leg intersection with median acceleration lanes.

In wider medians, where the opposing left-turn lanes do not overlap, median acceleration lanes can typically be provided within the width used for the conventional left-turn lane in that same direction of travel. Thus, median acceleration lanes can be incorporated in many existing designs without widening the median. However, the presence of a median acceleration lane reduces the amount by which the conventional left-turn lane for the opposing direction of travel on the divided highway can be offset. Thus, providing an operational and safety advantage for left turns onto the divided highway may create an operational and safety disadvantage for left turns from the divided highway.

A 1986 survey by the Institute of Transportation Engineers (ITE) found that median acceleration lanes had been used by 13 of the 53 highway agencies (25 percent) that responded to the survey (*12*). Respondents to the survey were divided evenly for and against the use of median acceleration lanes. ITE concluded that median acceleration lanes appear to promote efficient left turns onto major roadways and to reduce accidents and traffic conflicts but that insufficient data are available to quantify their traffic operational and safety benefits.

On the basis of the guidelines used by state highway agencies, acceleration lanes for left-turning vehicles from a crossroad onto the divided highway should be considered at locations where adequate median width is available and the following are true:

1. Limited gaps are available in the major-road traffic stream.
2. Turning traffic must merge with high-speed through traffic.
3. There is a significant history of rear-end or sideswipe accidents.
4. ISD is inadequate.
5. There are high volumes of trucks entering the divided highway.

One highway agency guideline stated that a truck volume of 75 to 100 trucks per day would be sufficient to warrant a median acceleration lane.

Indirect Left-Turn Treatments

The AASHTO Green Book presents design policies dealing with indirect left-turn treatments on pages 768 through 774. The indirect left-turn treatments presented in the Green Book for left turns off a divided highway include the use of jughandle roadways before the crossroad, loop roadways beyond the crossroad, and directional median crossovers beyond the crossroad. Such

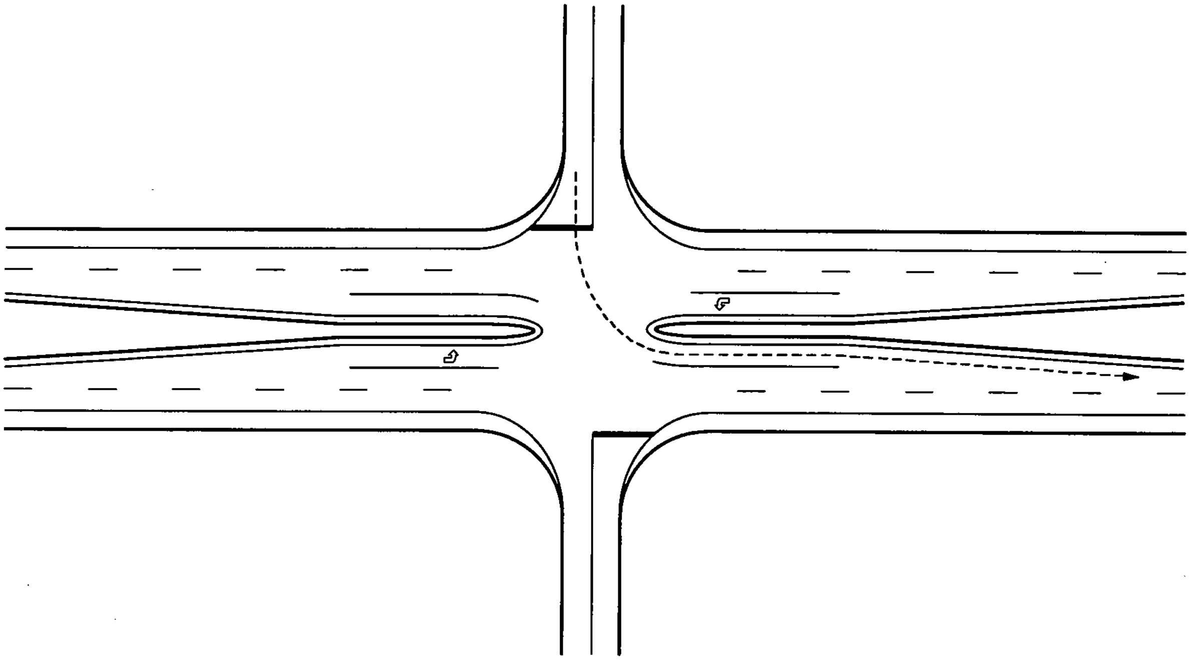


Figure 9. Typical four-leg divided highway intersection with median acceleration lanes.

treatments are typically used at major signalized intersections on divided highways, often in suburban areas. Figure 10 illustrates the indirect left-turn treatments identified above. The figure shows that each of these indirect left-turn treatments for left turns from the divided highway has a corresponding treatment for left turns onto the divided highway.

Indirect left-turn treatments are relevant to the selection of median widths because indirect left-turn treatments may permit a narrower median than would otherwise be possible. In other words, at some locations, the need to provide left-turn lanes in the median may be the controlling factor in the selection of the median width, and the use of indirect left-turn treatments can minimize this factor. Indirect left-turn treatments have been used extensively on suburban arterials in Michigan and New Jersey.

U-Turn Treatments

Median width requirements to permit U-turns through the median of a divided highway, at intersections or on directional crossover roadways, are presented in Figure 11, based on Green Book Figure IX-69. This figure is based on U-turns on a four-lane divided roadway, although the final row in the figure labeled "inner lane to shoulder" can be applied to turns into the outer lane of a six-lane divided roadway. The design vehicles on which the figure is based are those presented in Green Book Table II-1.

Median Openings

Minimum Length of Median Opening

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

Figure 12 and Table 3 illustrate the AASHTO criteria for minimum design of median openings on the basis of a 15-m (50-ft) control radius; this figure and table are analogous to the figures and tables presented in the Green Book for the other control radii.

The definition of the control radius was illustrated earlier in Figure 5. The control radius is selected as follows:

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

The Green Book also presents above-minimum median opening design appropriate for control radii of 30, 50, and 70 m (90, 150, and 230 ft) (see Figure 13) on the basis of Green Book Figure IX-64. Such designs can provide for design vehicles larger than the WB-15 truck (which is a relatively small combination truck in today's fleet) and will permit WB-15 and smaller trucks to turn at speeds higher than 15 to 25 km/hr (10 to 15 mph) without encroaching on adjacent lanes.

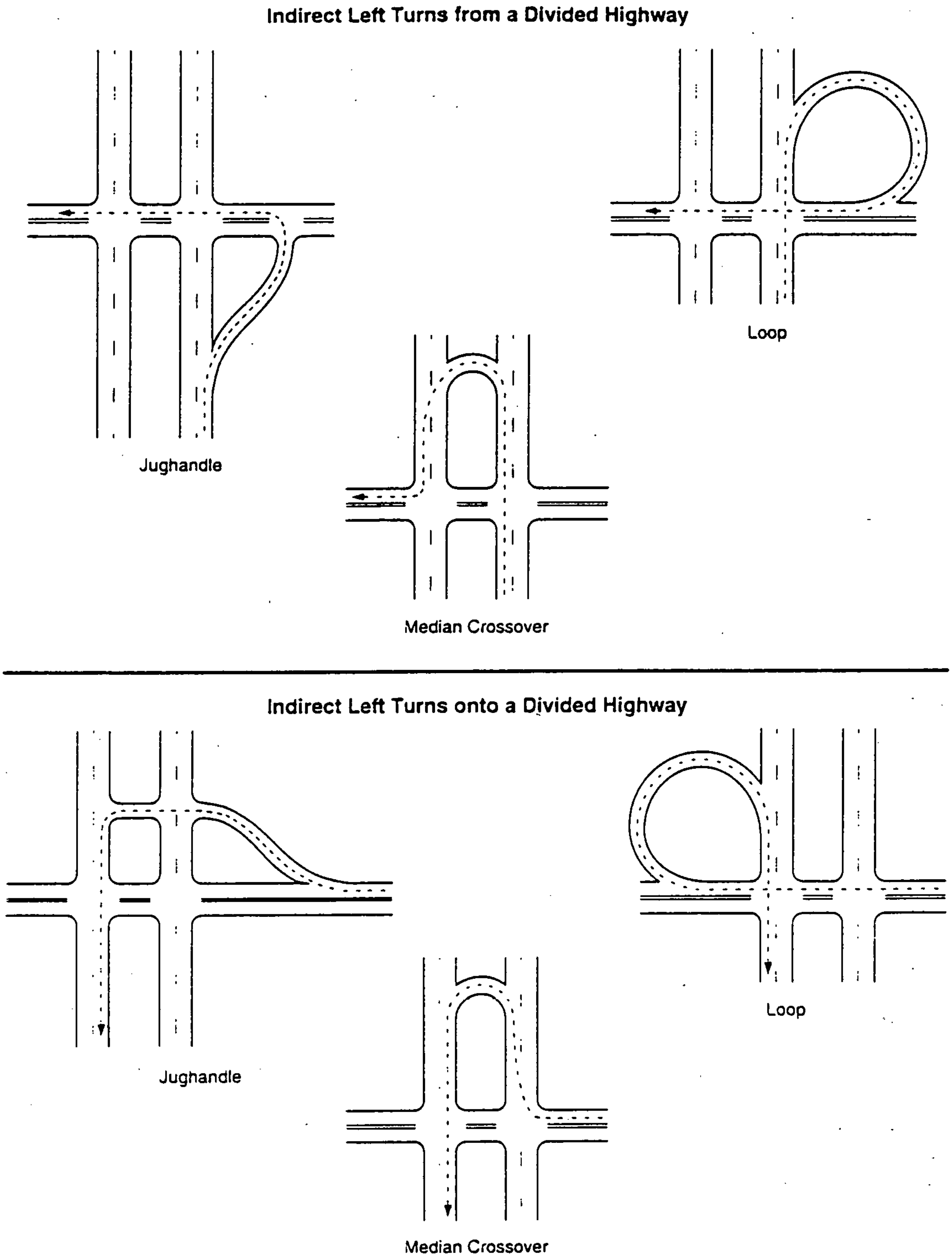


Figure 10. Examples of indirect left-turn treatments for divided highway intersections.

Median Nose Treatments

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

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

One state highway agency reported that it had evaluated a squared median nose in comparison with a bullet nose. The

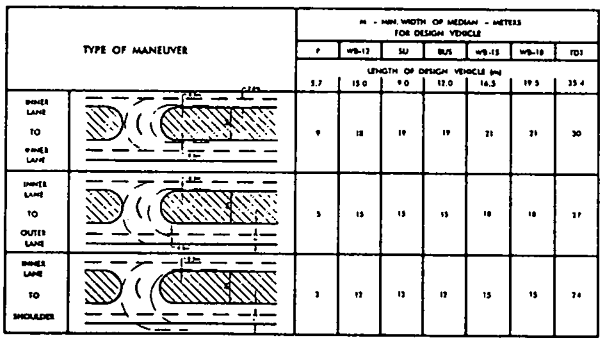
results of the study indicated that the bullet nose had several advantages over the squared end, including fewer accidents, more intersection capacity, and the ability to provide for a full range of signal phasing (*13*).

Spacing Between Median Openings

Very few state highway agency design policies were found to have formal provisions for the minimum spacing between median openings. One state highway agency recommended that median openings in urban/suburban areas be spaced no closer than 488 m (1,600 ft) apart if the intersections are to be signalized. For unsignalized intersections, the spacing requirement is such that exclusive left-turn lanes with the proper taper and storage lengths can be provided.

In rural areas, one state highway agency recommends a minimum spacing of 0.4 km (0.25 mi) between median openings and a maximum spacing of 0.8 km (0.5 mi). Another state uses a minimum spacing of 0.8 to 1.6 km (0.5 to 1.0 mi) between median openings on divided highways, unless existing intersections require closer spacing. Still another state tries to maintain an average 1.6-km (1-mi) spacing between median openings on rural divided highways with partial control of access on new alignments and an average spacing of 0.8 km (0.5 mi) between median openings along existing roadways.

In rural areas, median openings are normally provided at all intersections with public roads. Most states do not provide median openings for all driveways, although openings may be warranted for higher-volume commercial or industrial driveways. However, at least one state highway agency reported providing median openings for all driveways along extended sections of divided highways.



TYPE OF MANEUVER	M - MIN. WIDTH OF MEDIAN - METERS 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	3	12	13	12	15	15	24

Figure 11. AASHTO minimum median widths to accommodate U-turns (1).

SAFETY CHARACTERISTICS OF DIVIDED HIGHWAYS AND DIVIDED HIGHWAY INTERSECTIONS

Recent Data on the Safety Performance of Divided Highways and Intersections

Multilane divided highways, in general, experience some of the lowest accident rates of any type of nonfreeway facility.

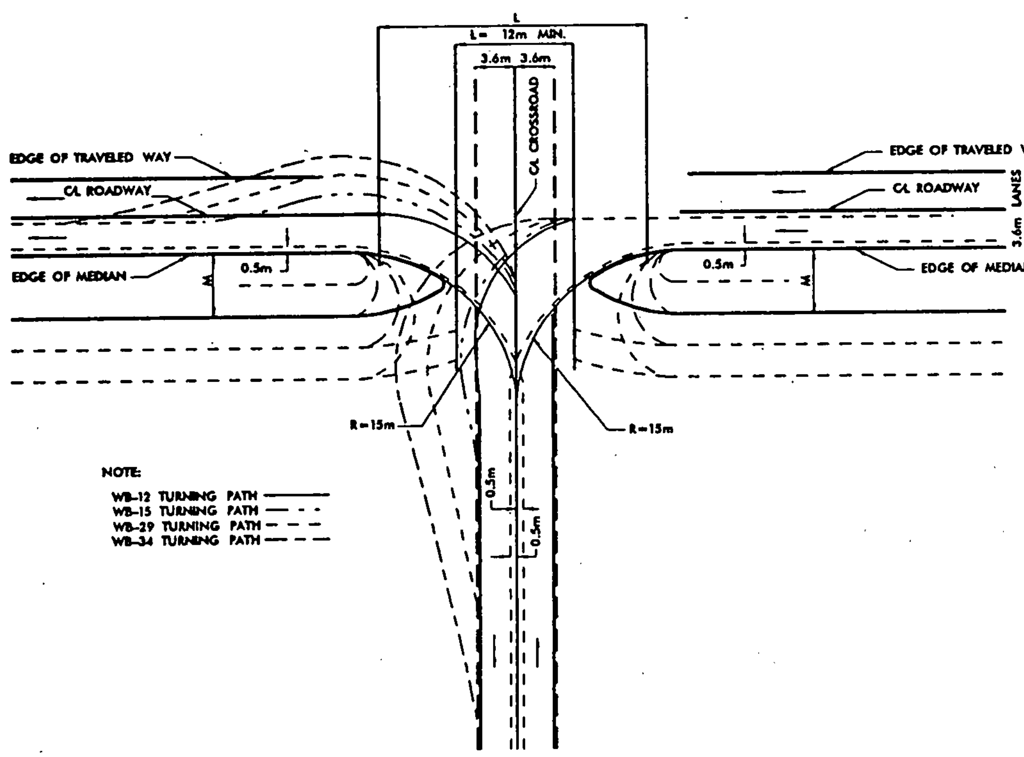
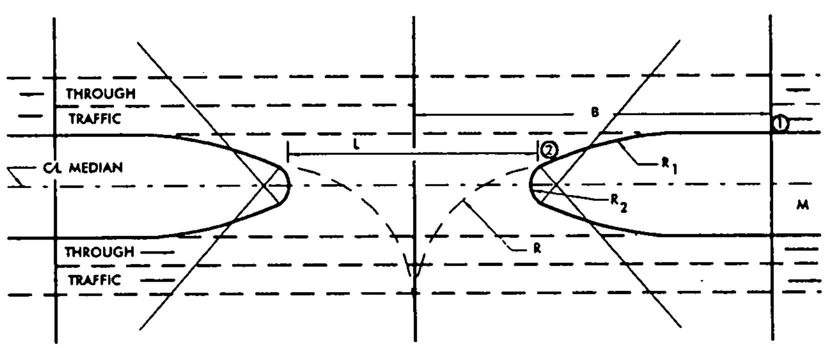


Figure 12. Minimum design of median openings (SU design vehicle, control radius of 15 m) (1).

TABLE 3. Minimum design of median openings (SU design vehicle, control radius of 15 m) (*1*)

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



ASSUMED R = 15m
$R_2 = M/5$

M WIDTH OF MEDIAN, METERS	DIMENSIONS IN METERS WHEN					
	R_1 = 30m		R_1 = 50m		R_1 = 70m	
	L	b	L	b	L	b
6.0	17.4	19.5	19.8	23.4	21.3	27.0
9.0	14.4	20.4	17.1	25.5	18.9	30.3
12.0	13.0	21.3	15.0	27.0	17.1	32.7
15.0	—	—	13.7	28.5	15.3	39.5
18.0	—	—	—	—	13.8	36.6
21.0	—	—	—	—	12.3	38.4

Figure 13. Above-minimum design of median openings (typical bullet nose ends) (1).

For example, recent California data show that, for nonfreeway facilities in rural areas, including both intersection and nonintersection accidents, multilane divided highways have lower accident rates than two-lane highways and multilane undivided highways. In urban and suburban areas in California, the accident rates of multilane divided highways were lower than for multilane undivided highways but higher than for two-lane highways (*14*). Similar data show that accident rates on rural multilane

TABLE 4. Summary of accident rates by roadway type reported in the literature (14, 15)

Highway and area type	Accident rate (per million veh-km) California[a]	Accident rate (per million veh-km) Minnesota[b]	Accident rate (per million veh-km) Utah[b]	Accident rate (per million veh-mi) California[a]	Accident rate (per million veh-mi) Minnesota[b]	Accident rate (per million veh-mi) Utah[b]
RURAL HIGHWAYS						
Two-lane undivided highways	0.82	1.11	1.31	1.32	1.79	2.10
Multilane undivided highways	1.32	4.44	1.41	2.13	7.14	2.27
Multilane divided highways	0.71	1.47	1.38	1.15	2.37	2.22
URBAN HIGHWAYS						
Two-lane undivided highways	1.35	--	--	2.17	--	--
Multilane undivided highways	2.23	--	--	3.59	--	--
Multilane divided highways	1.60	--	--	2.58	--	--

[a] Based on 1991 data; includes only roadways with uncontrolled access.
[b] Based on 1987 data from the FHWA Highway Safety Information System.

TABLE 5. Accident data for rural multilane divided highways in Minnesota and Utah by severity level and relationship to intersection—1987 (15)

Relationship to Intersection	Annual Number of Accidents F+I	Annual Number of Accidents PDO	Annual Number of Accidents TOTAL	% of Accidents by Relationship to Intersection F+I	% of Accidents by Relationship to Intersection PDO	% of Accidents by Relationship to Intersection TOTAL
MINNESOTA						
Intersection accidents	266	363	629	69.6	32.3	41.8
At–intersection	220	284	504	57.6	25.3	33.5
Intersection–related	46	79	125	12.0	7.0	8.3
Non–intersection accidents	116	760	876	30.4	67.7	58.2
TOTAL	382	1123	1505	100.0	100.0	100.0
UTAH						
Intersection accidents	--	--	--	--	--	--
At–intersection	58	101	159	43.0	30.7	34.3
Intersection–related	--	--	--	--	--	--
Non–intersection accidents	77	228	305	57.0	69.3	65.7
TOTAL	135	329	464	100.0	100.0	100.0

divided highways in Minnesota are much lower than the accident rates of rural multilane undivided highways, while in Utah the accident rates of rural multilane divided and undivided highways are about the same (*15*). This difference probably results from higher levels of development in Minnesota than in Utah. These data are summarized in Table 4 and include highways with partial access control and with no access control.

Table 5 presents a breakdown of the Minnesota and Utah accident data for rural multilane divided highways by relationship to intersection and accident severity (*15*). The Minnesota data show that approximately 34 percent of the accidents on rural divided highways occur at intersections, while another 8 percent of accidents are intersection related, even though they occur outside the curbline limits of the intersection. Forty-two percent of divided highway accidents in Minnesota are related to intersections, which illustrates that intersections obviously constitute an important issue in safety management of divided highways.

The Utah data in Table 5 show that accidents at intersections constitute 34 percent of all accidents on rural divided highways, a statistic that is comparable with the Minnesota experience. Unfortunately, the Utah data do not identify intersection-related accidents that occur outside the curbline limits of the intersection.

The accident severity data for Minnesota in Table 5 show that approximately 42 percent of intersection accidents involved a fatality or injury. By contrast, only 13 percent of nonintersection accidents involved a fatality or injury. The finding that intersection accidents tend to be more severe than nonintersection accidents is also confirmed in the Utah data. This finding is another indication of the importance of intersections in safety management of divided highways.

Table 6 presents the distribution of accident types for roadway section accidents in Minnesota. The table classifies accidents by the number of vehicles involved, collision type, relationship to intersection, and location of first harmful event (on roadway/off roadway). The table shows that 97 percent of at-intersection accidents and 78 percent of other intersection-related accidents involve multiple-vehicle collisions on the roadway. In contrast, multiple-vehicle collisions constitute only 29 percent of nonintersection accidents. Thus, the single-vehicle run-off-road accident problem, which predominates safety management between intersections in rural areas, is not a major issue in intersection accidents. The goal of safety management at divided highway

intersections should clearly be to minimize multiple-vehicle collisions. This finding is generally confirmed by the Utah accident type distribution data in Table 7, although the percentage of intersection-related accidents that involve multiple-vehicle collisions is lower in Utah than in Minnesota.

Research Findings Concerning Safety Performance of Divided Highway Intersections

Two published research studies—one in California and one in Ohio—have addressed the safety performance of divided highway intersections. Both of these studies were performed a number of years ago, one in the 1950s and the other in the 1960s.

A 1953 California study by McDonald (*16*) 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 no direct relationship existed between intersection accidents and the sum of the entering traffic volumes; thus, the study did not support the use of accidents per million entering vehicles as a safety measure of effectiveness. On the other hand, the study also found that it was inappropriate to use an exposure index based on the product of the intersecting volumes because the accident experience at divided highway intersections was found to be more sensitive to the minor-road ADT than to the divided highway ADT. The following relationship was found to best describe

TABLE 6. Distribution of accident types for rural multilane divided nonfreeways in Minnesota—1987 (*15*)

	Roadway section accidents						At-intersection accidents						Other intersection-related accidents						TOTAL ACCIDENTS	
	On-roadway		Run-off road		Combined		On-roadway		Run-off road		Combined		On-roadway		Run-off road		Combined			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
SINGLE-VEHICLE ACCIDENTS	291	53.5	332	100.0	623	71.1	17	3.5	25	100.0	42	8.3	9	8.4	18	100.0	27	21.6	692	46.0
Noncollision accidents	30	5.5	138	41.6	168	19.2	4	0.8	5	20.0	9	1.8	1	0.9	9	50.0	10	8.0	187	12.4
Overturned	24	4.4	122	36.7	146	16.7	2	0.4	5	20.0	7	1.4	1	0.9	9	50.0	10	8.0	163	10.8
Other noncollision	6	1.1	16	4.8	22	2.5	2	0.4	0	0.0	2	0.4	0	0.0	0	0.0	0	0.0	24	1.6
Collision accidents	261	48.0	194	58.4	455	51.9	13	2.7	20	80.0	33	6.5	8	7.5	9	50.0	17	13.6	505	33.6
Coll. w/ pedestrian	1	0.2	1	0.3	2	0.2	1	0.2	0	0.0	1	0.2	2	1.9	0	0.0	2	1.6	5	0.3
Coll. w/ bicycle	1	0.2	0	0.0	1	0.1	2	0.4	0	0.0	2	0.4	0	0.0	0	0.0	0	0.0	3	0.2
Coll. w/ animal	243	44.7	2	0.6	245	28.0	3	0.6	0	0.0	3	0.6	3	2.8	0	0.0	3	2.4	251	16.7
Coll. w/ parked vehicle	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Coll. w/ fixed object	13	2.4	184	55.4	197	22.5	7	1.5	20	80.0	27	5.4	3	2.8	8	44.4	11	8.8	235	15.6
Coll. w/ other object	3	0.6	4	1.2	7	0.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	7	0.5
Other collision	0	0.0	3	0.9	3	0.3	0	0.0	0	0.0	0	0.0	0	0.0	1	5.6	1	0.8	4	0.3
MULTIPLE-VEHICLE ACCIDENTS	253	46.5	0	0.0	253	28.9	462	96.5	0	0.0	462	91.7	98	91.6	0	0.0	98	78.4	813	54.0
Head-on	11	2.0	0	0.0	11	1.3	2	0.4	0	0.0	2	0.4	1	0.9	0	0.0	1	0.8	14	0.9
Sideswipe (same dir)	52	9.6	0	0.0	52	5.9	15	3.1	0	0.0	15	3.0	15	14.0	0	0.0	15	12.0	82	5.4
Sideswipe (opp dir)	11	2.0	0	0.0	11	1.3	1	0.2	0	0.0	1	0.2	3	2.8	0	0.0	3	2.4	15	1.0
Angle or turning	22	4.0	0	0.0	22	2.5	334	69.7	0	0.0	334	66.3	24	22.4	0	0.0	24	19.2	380	25.2
Rear-end	102	18.8	0	0.0	102	11.6	60	12.5	0	0.0	60	11.9	39	36.4	0	0.0	39	31.2	201	13.4
Other MV collision	55	10.1	0	0.0	55	6.3	50	10.4	0	0.0	50	9.9	16	15.0	0	0.0	16	12.8	121	8.0
TOTAL ACCIDENTS	544	100.0	332	100.0	876	100.0	479	100.0	25	100.0	504	100.0	107	100.0	18	100.0	125	100.0	1505	100.0

TABLE 7. Distribution of accident types for rural multilane divided nonfreeways in Utah—1987 (*15*)

	Roadway section accidents						Intersection accidents						TOTAL ACCIDENTS	
	On-roadway		Run-off-road		Combined		On-roadway		Run-off-road		Combined			
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
SINGLE-VEHICLE ACCIDENTS	106	45.7	73	100.0	179	58.7	14	9.1	5	100.0	19	11.9	198	42.7
Noncollision accidents	8	3.4	53	72.6	61	20.0	5	3.2	1	20.0	6	3.8	67	14.4
Overturned	3	1.3	0	0.0	3	1.0	3	1.9	0	0.0	3	1.9	6	1.3
Other noncollision	5	2.2	53	72.6	58	19.0	2	1.3	1	20.0	3	1.9	61	13.1
Collision accidents	98	42.2	20	27.4	118	38.7	9	5.8	4	80.0	13	8.2	131	28.2
Coll. w/ pedestrian	3	1.3	0	0.0	3	1.0	3	1.9	0	0.0	3	1.9	6	1.3
Coll. w/ bicycle	2	0.9	0	0.0	2	0.7	3	1.9	0	0.0	3	1.9	5	1.1
Coll. w/ animal	81	34.9	0	0.0	81	26.6	1	0.6	0	0.0	1	0.6	82	17.7
Coll. w/ parked vehicle	8	3.4	0	0.0	8	2.6	1	0.6	0	0.0	1	0.6	9	1.9
Coll. w/ fixed object	0	0.0	20	27.4	20	6.6	0	0.0	4	80.0	4	2.5	24	5.2
Coll. w/ other object	3	1.3	0	0.0	3	1.0	0	0.0	0	0.0	0	0.0	3	0.6
Other collision	1	0.4	0	0.0	1	0.3	1	0.6	0	0.0	1	0.6	2	0.4
MULTIPLE-VEHICLE ACCIDENTS	126	54.3	0	0.0	126	41.3	140	90.9	0	0.0	140	88.1	266	57.3
Head-on	4	1.7	0	0.0	4	1.3	2	1.3	0	0.0	2	1.3	6	1.3
Sideswipe (same dir)	16	6.9	0	0.0	16	5.2	3	1.9	0	0.0	3	1.9	19	4.1
Sideswipe (opp dir)	6	2.6	0	0.0	6	2.0	0	0.0	0	0.0	0	0.0	6	1.3
Angle or turning	53	22.8	0	0.0	53	17.4	110	71.4	0	0.0	110	69.2	163	35.1
Rear-end	44	19.0	0	0.0	44	14.4	24	15.6	0	0.0	24	15.1	68	14.7
Other MV collision	3	1.3	0	0.0	3	1.0	1	0.6	0	0.0	1	0.6	4	0.9
TOTAL ACCIDENTS	232	100.0	73	100.0	305	100.0	154	100.0	5	100.0	159	100.0	464	100.0

the relationship between the number of accidents and the traffic volume at divided highway intersections:

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

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)

It should be noted that, in this relationship, the number of accidents at a divided highway intersection is proportional to the product of the intersecting volumes, where each of the volumes is reduced by being raised to an exponent of less than one. The exponent for the crossroad volume is larger than the exponent for the divided highway volume, indicating the greater sensitivity of accident experience to crossroad volume.

Figure 14 illustrates the relationship between traffic volume and accident frequency represented by equation 1. The figure can be entered with the ADTs of the divided highway and crossroad to determine the expected number of intersection accidents per year.

On the basis of the relationships in equation 1 and Figure 14, McDonald concluded that low-crossroad-volume intersections have higher accident rates per crossroad vehicle than do high-crossroad-volume intersections. 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.

A study very similar to the McDonald study was conducted in Ohio by Priest (*17*) in 1964. The Priest study included 3 years of accident data for 316 at-grade intersections on divided highways with partial or no control of access. Most, if not all, of the intersections studied were evidently unsignalized intersections; however, the author does not explicitly state the type of traffic control used at the intersections studied. Priest concluded that accident frequency at divided highway intersections increases with the product of the intersecting traffic volumes. However, like McDonald, Priest also found that accident frequency is more sensitive to the crossroad traffic volume than to the divided highway traffic volume.

Figure 15 shows the relationship between traffic volume and accident frequency developed by Priest, which appears very similar to the relationship for California developed by McDonald, although it covers a higher range of crossroad volumes and a lower range of divided highway volumes. The findings of the Priest study concerning the safety effects of different median widths are presented later in the median width discussion.

Table 8 compares the annual accident frequencies for divided highway intersections predicted by the McDonald and Priest studies. Although the ADT ranges of the two studies have only limited overlap, the accident frequency predictions within the ADT range common to both studies are mutually supportive.

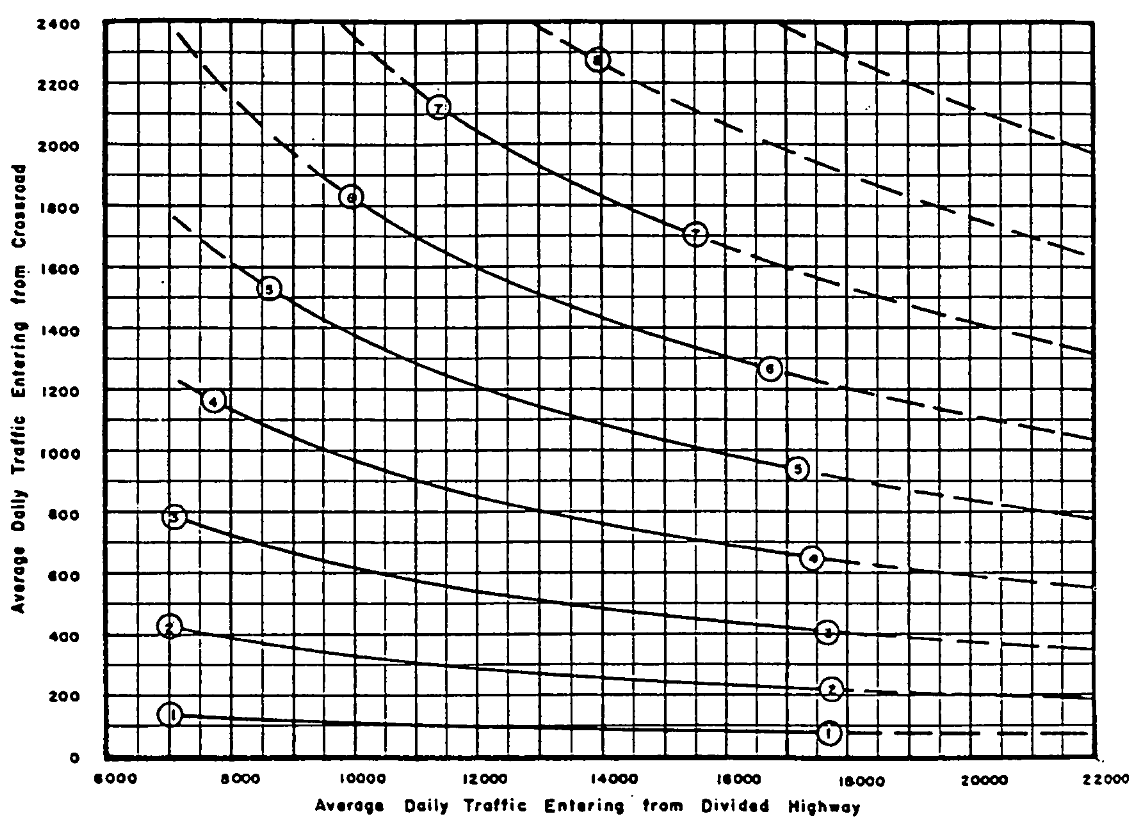


Figure 14. Average number of accidents per year related to traffic volume at divided highway intersections—California (16).

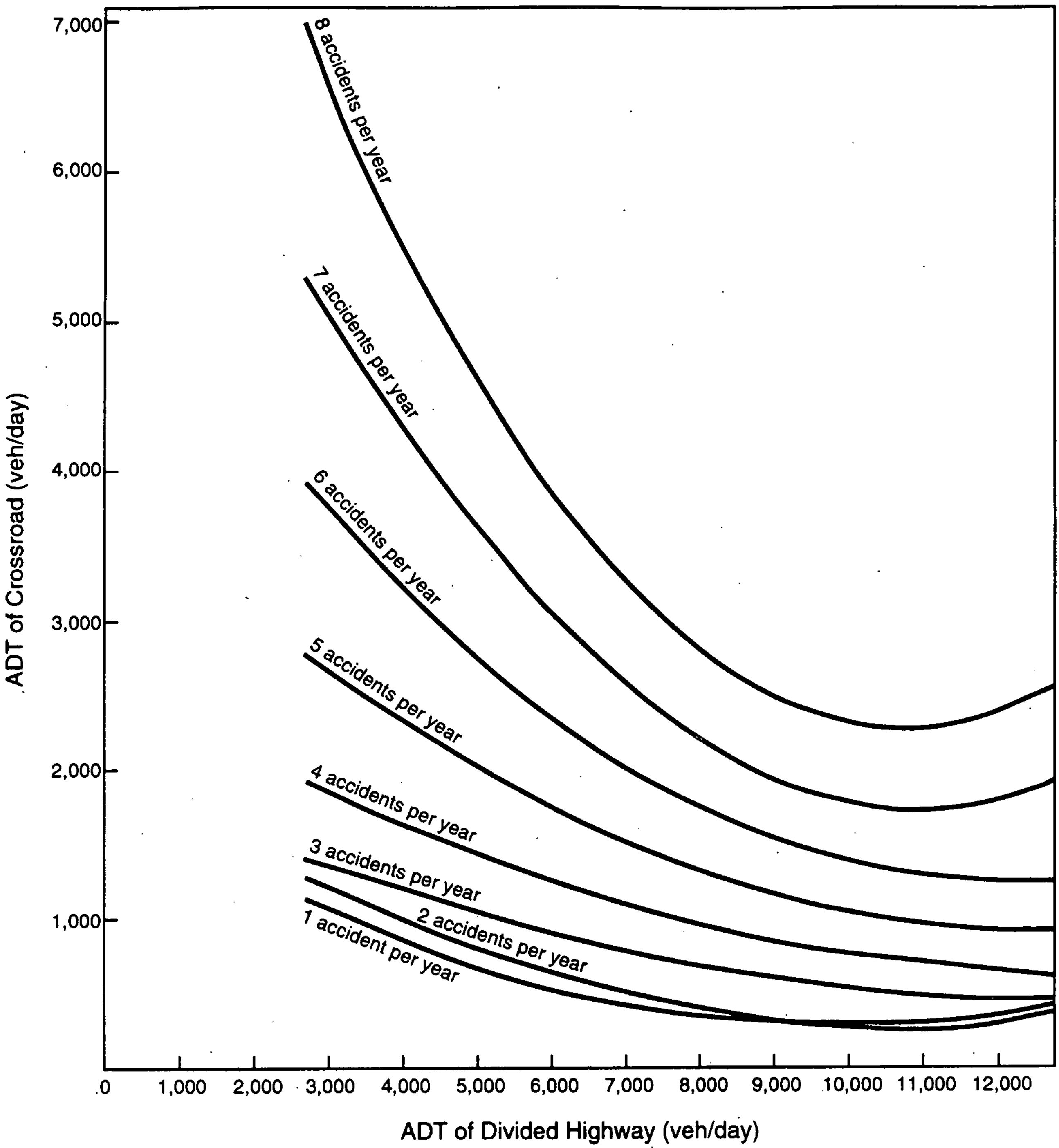


Figure 15. Average number of accidents per year related to traffic volume at divided highway intersections—Ohio (17).

TRAFFIC SAFETY AND OPERATIONAL EFFECTS OF MEDIAN WIDTH

This section presents the findings concerning the analysis of the traffic safety and operational effects of median width and median opening length at divided highway intersections. The discussion includes findings drawn from current knowledge in the literature, the accident analysis of divided highway intersections in California, the field observational studies, and the accident analysis of field observational study sites. All statements concerning statistical significance in this discussion are at the 95 percent confidence level, unless otherwise stated.

Current Knowledge

Effects of Median Width Between Intersections

Most past research on divided highway median width has focused on the effects of median width between intersections

TABLE 8. Comparison of predicted annual accident frequency for divided highway intersections as a function of intersection traffic volumes for California and Ohio (*16, 17*)

Minor Road ADT (veh/day)	EXPECTED ANNUAL NUMBER OF ACCIDENTS PER INTERSECTION — Divided Highway ADT (veh/day) 3000	4000	5000	7500	10000	15000	20000
CALIFORNIA (1953)							
100	--	--	--	0.8	1.0	1.1	1.3
500	--	--	--	2.3	2.6	3.2	3.6
1000	--	--	--	3.6	4.1	4.9	5.6
2000	--	--	--	5.6	6.4	7.6	8.7
3000	--	--	--	--	--	--	--
4000	--	--	--	--	--	--	--
5000	--	--	--	--	--	--	--
6000	--	--	--	--	--	--	--
OHIO (1964)							
100	0.1	0.1	0.1	0.3	0.4	--	--
500	0.5	0.6	0.7	2.2	2.8	--	--
1000	0.9	2.0	2.8	3.8	4.8	--	--
2000	4.3	4.5	5.0	5.2	7.4	--	--
3000	5.4	5.8	6.3	8.2	--	--	--
4000	6.2	6.7	7.4	--	--	--	--
5000	7.0	7.6	--	--	--	--	--
6000	7.6	--	--	--	--	--	--

rather than at intersections. For example, it is known that the presence of a median on a divided highway provides a definite improvement in traffic operations compared with an undivided highway. The multilane highway analysis procedure in Chapter 7 of the *Highway Capacity Manual* (*3*) estimates that the free-flow speed on a divided highway is generally 2.6 km/h (1.6 mph) higher than on a comparable undivided highway. However, the median width itself has no documented effect on traffic operations, unless a very narrow median necessitates the location of median barriers or other lateral obstructions within 1.8 m (6 ft) of the traveled way.

Providing medians between intersections is desirable to reduce the likelihood that vehicles whose drivers are inattentive or lose control will run into the opposing lanes of traffic. The safety effects of median width between intersections have been addressed in a number of studies (*18,19,20,21,22 ,23*). These studies generally show a decrease in accident rate between intersections with increasing median width of up to approximately 12 m (40 ft). For median widths between intersections in the range from 12 to 24 m (40 to 80 ft), there are mixed results; some studies show that accident rate continues to decrease with increasing median width, while others show no relationship. Almost no research has addressed the safety effects of medians wider than 24 m (80 ft).

These findings suggest that minimum median widths of 12 m (40 ft) be provided between intersections when possible. Medians wider than 12 m (40 ft) between intersections may be desirable, but safety benefits of wider medians have not been conclusively demonstrated.

Effects of Median Width at Intersections

Less information is published about the effects of median widths at intersections than between intersections. The 1964 Ohio study by Priest (*17*), described in the previous section, established relationships between the number of intersection accidents per year and the exposure index for different ranges of median width. The exposure index used by Priest is the product of the ADTs of the intersecting roadways. These relationships are illustrated in Figure 16. For any given value of the exposure index, the differences in accident rate between the three median-width groups shown in the figure represent differences in both accident frequency and in accident rate, because they compare accident experience for equivalent entering traffic volumes. The relationships in the figure show that, except at very low volume levels, intersection accident rates decrease with increasing median width. However, the difference in accident rate 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.

A 1977 Purdue University study by Van Maren (*24*) 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

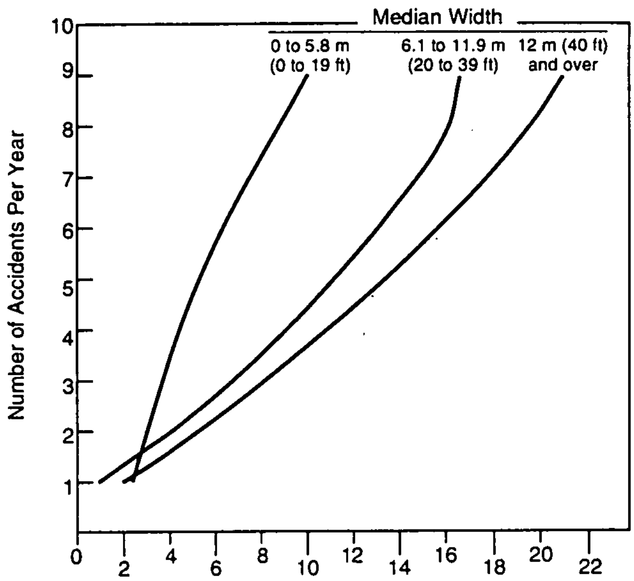


Figure 16. Variation of annual accident frequency at divided highway intersections as a function of median width and exposure index (the product of the ADTs of the intersecting roadways) (17).

divided nonfreeways that have been built by highway agencies since the 1950s, including current practices. Van Maren found that larger Stop signs, advance warning signs, and marked stop lines on the crossroad approaches decreased accidents. Accident rate was found to increase as the length of the travel path across the intersection, for a crossing or turning vehicle, increased. On the basis of this finding, Van Maren recommended that the distance across the intersection be minimized by reducing the distance between the stop line on the crossroad approach and the edge of the major-road traveled way, whenever possible; the author was careful to say that the distance across the intersection should not be shortened by decreasing the median width.

Research by Radwan et al. (*25,26,27*) at Purdue University in 1979 used field studies and simulation modeling to investigate the operational effects of median width and traffic control at both signalized and unsignalized intersections on divided highways. On the basis of simulation modeling with an early version of NETSIM applied at unsignalized intersections, Radwan et al. generally found no statistically significant effect of median width on traffic delays and traffic conflicts over the range of median widths from 9 to 18 m (30 to 60 ft).

Accident Analyses Using Statewide Data for Divided Highways in California

A traffic accident analysis of divided highway intersections was conducted with a statewide data base of accident, geometric, traffic control, and traffic volume data for state highways in California. Data were extracted from this data base for five specific types of divided highway intersections:

- Rural, four-leg, unsignalized intersections with stop control on the crossroad approach
- Rural, three-leg, unsignalized intersections with stop control on the crossroad approach
- Urban/suburban, four-leg, unsignalized intersections with stop control on the crossroad approach
- Urban/suburban, three-leg, unsignalized intersections with stop control on the crossroad approach
- Urban/suburban, four-leg, signalized intersections

In general, this research focused on rural and suburban intersections. The California data base did not provide an explicit method to distinguish between urban and suburban intersections in accordance with the definitions used in the rest of this research. Therefore, all urban and suburban intersections in the California data base were analyzed together. However, most divided highway intersections on state highways in California are suburban, rather than urban.

Table 9 summarizes the accident data for the five intersection types listed above. The five intersection types included a total of 2,140 divided intersections with median widths of 4 m (14 ft) or greater. The accident analysis was restricted to multiple-vehicle accidents within the curbline limits of each intersection. This restriction was made because it appeared unlikely that median width would have any direct causal relationship to either multiple-vehicle accidents that occurred outside the curbline limits of the intersection or to single-vehicle accidents. In a 3-year analysis period (1990—1992), the 2,140 intersections experienced a total of 8,748 multiple-vehicle accidents. The rural, three-leg, unsignalized intersections had the fewest number of accidents (approximately 0.6 multiple-vehicle accidents per intersection per year), while the urban/suburban, four-leg, signalized intersections had the most accidents (approximately 2.6 multiple-vehicle accidents per intersection per year).

The statistical techniques used to evaluate the effect of median width on accident experience included one-way analysis of variance, Poisson regression, and log-linear regression. One-way analysis of variance was used to take a first look at whether the apparent trends in accident rate with changing median width shown in Table 9 were statistically significant.

Analysis of variance is a statistical technique to evaluate relationships between a continuous dependent variable (in this case, accident rate per million entering vehicles) and a categorical or discrete independent variable (in this case, median width divided into the five levels shown in Table 9).

A major limitation of the one-way analysis of variance was that only one independent variable — major-road median width—was evaluated. Therefore, an alternative analysis method that could simultaneously consider the effects of several independent variables, including the major-road median width and other key geometric elements of the intersection design, was considered. The consideration of multiple independent variables in the same analysis is intended to ensure that an effect of one of these other variables is not mistaken for an effect of median width or does not obscure an effect of median width. Table 10 lists the variables from the existing California data base that were considered in these analyses.

In past research, predictive models for accident rate have typically been developed using a variation of the general linear model: multiple regression analysis in which all independent variables are continuous and quantitative; analysis of variance where all variables are categorical; and analysis of covariance where both continuous and categorical variables are present.

TABLE 9. Accident rate for divided highway intersections in California for selected ranges of median width

Median width	Number of intersections[a]	Number of accidents[b]	Exposure (million entering vehicles)	Accident rate (per million entering vehicles)
RURAL FOUR-LEG UNSIGNALIZED INTERSECTIONS				
14 to 28 ft	66	206	845.6	0.24
30 to 50 ft	43	173	1261.9	0.14
52 to 80 ft	31	76	517.2	0.15
82 to 100 ft	6	2	39.6	0.05
over 100 ft	7	6	87.2	0.07
	153	463	2751.5	
RURAL THREE-LEG UNSIGNALIZED INTERSECTIONS				
14 to 28 ft	99	154	1698.8	0.09
30 to 50 ft	35	102	1080.1	0.09
52 to 80 ft	9	12	189.2	0.06
82 to 100 ft	4	1	26.9	0.04
over 100 ft	10	2	109.1	0.02
	157	271	4808.1	
URBAN/SUBURBAN FOUR-LEG UNSIGNALIZED INTERSECTIONS				
14 to 28 ft	246	962	8009.6	0.12
30 to 50 ft	31	214	1022.7	0.21
52 to 80 ft	15	153	507.6	0.30
82 to 100 ft	0	0	0.0	--
over 100 ft	1	5	22.9	0.22
	293	1344	9562.8	
URBAN/SUBURBAN THREE-LEG UNSIGNALIZED INTERSECTION				
14 to 28 ft	829	1541	31069.9	0.05
30 to 50 ft	57	128	1854.9	0.07
52 to 80 ft	19	33	674.4	0.05
82 to 99 ft	1	1	41.1	0.02
over 100 ft	1	0	75.7	0.00
	907	1703	33716.0	
URBAN/SUBURBAN FOUR-LEG SIGNALIZED INTERSECTIONS				
14 to 28 ft	551	4166	27184.4	0.15
30 to 50 ft	46	355	1856.6	0.19
52 to 80 ft	29	411	1281.4	0.31
82 to 99 ft	0	0	0.0	--
over 100 ft	4	35	199.6	0.18
	630	4967	30522.0	

[a] Includes all suitable intersections on the California state highway system.

[b] Includes reported accidents of all severity levels for a 3-year period (1990-1992); includes only multiple-vehicle accidents that occurred within the curb line limits of the intersection.

[c] Total number of million vehicles entering the intersections in a 3-year period based on the best available estimates of major-road and crossroad ADT.

TABLE 10. Geometric, traffic control, and traffic volume variables available for divided highway intersections in the California data base

- Major-road average daily traffic volume (veh/day)
- Crossroad average daily traffic volume (veh/day)
- Major-road median width (ft)
- Functional class of major road
- Design speed of major road (mi/h)
- Access control on major road (partial/none)
- Number of lanes on major road
- Number of lanes on crossroad
- Average lane width on major road (ft)
- Outside shoulder width on major road (ft)
- Presence of left-turn lanes on major road (yes/no)
- Presence of left-turn lanes on crossroad (yes/no)
- Presence of right-turn channelization on major road (yes/no)
- Presence of right-turn channelization on crossroad (yes/no)
- Terrain (flat/rolling/mountainous)
- Intersection lighting (yes/no)
- Signal phasing (2-phase vs. multiphase) (for signalized intersections only)
- Presence of signal mast arms on major road (yes/no) (for signalized intersections only)
- Presence of signal mast arms on crossroad (yes/no) (for signalized intersections only)

These statistical methods were initially used because they were familiar to researchers and were justified on the basis that, for large samples at least, the various statistics should be approximately normal. The general linear model makes the assumption that the dependent variable — in this case, accident frequencies — follows a normal distribution. Researchers have now found that these techniques based on the general linear model and the normal assumption are not well suited to accident analysis, because accidents are discrete and rare events whose distribution is better described by a discrete probability distribution.

Several candidate alternative analysis methods were reviewed for application to the accident frequencies at the divided highway intersections in this study. For each of the five types of intersections, the distribution of the 3-year total multiple-vehicle accident frequencies was examined. As explained in Appendix D, the accident frequency distributions for those intersections were found to be quite skewed. Most types of intersections experienced either no accidents or one accident over a 3-year period. A few intersections experienced 2 to 10 accidents yearly but rarely did an intersection experience more than 10 accidents yearly. This observation is not true for urban/suburban, four-leg, signalized intersections, where about 50 percent of the intersections experienced seven or more total multiple-vehicle accidents over the 3-year period, and only about 11 percent had either no accidents or one accident.

Upon review of these accident data distributions, it was concluded that two methods were the most appropriate for analyzing the intersection accident data in this study. Poisson regression was useful for analyzing the accident frequencies for all the rural and urban/suburban unsignalized intersections, which include many intersections with no or very few accidents in a 3-year period. The Poisson regression approach was unsuitable for analyzing the accident frequencies at the urban/suburban signalized intersections, which did not include many intersections with very few accidents; a log-normal regression approach was found to be more appropriate for analyzing the data for this intersection type.

The results of these analyses, (see Tables D-5 through D-9 in Appendix D) are presented as predictive models for multiple-vehicle accident frequency as a function of selected geometric and traffic control variables, including median width. The findings of these analyses concerning median width are as follows:

1. At rural, four-leg, unsignalized intersections, accident frequency decreases as median width increases. This result is statistically significant.
2. At rural, three-leg, unsignalized intersections, no statistically significant relationship exists between accident frequency and median width.
3. 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). This result is statistically significant.
4. At urban/suburban, three-leg, unsignalized intersections, there is a statistically significant relationship between median width and accident frequency. The intersection accident frequency increases with increasing median width.
5. At urban/suburban, four-leg, signalized intersections, accident frequency increases as median width increases over the range of median widths from 4 to 24 m (14 to 80 ft). This result is statistically significant.

It should be noted that the results stated above were found after accounting for the effects of as many of the other factors listed in Table 10 as possible.

Similar analyses using fatal and injury-producing multiple-vehicle accidents (rather than total multiple-vehicle accidents) as the dependent variable provided similar results, except that no statistically significant effect was found for fatal and injury accidents at urban/suburban, three-leg, unsignalized intersections.

Table 11 summarizes the effect of median width on multiple-vehicle intersection accident frequency. The table includes the effect of median width on accidents, expressed as a percentage, as well as upper and lower confidence limits for that effect. The effects in the table are the percentage change in multiple-vehicle intersection accident frequency that will result from a unit change in median width. Unit changes in median width of both 1 m and 1 ft are presented in the table. For example, the table shows that, at a rural, four-leg, unsignalized intersection, a 1-m increase in median width would be expected to decrease multiple-vehicle intersection accidents by 4.16 percent. Confidence limits for this effect are from 2 to 6.3 percent; this indicates that 95 percent of the time, the actual effect of median width on accidents would be expected in the range of 2 percent to 6.3 percent. For a unit increase of 1 ft in median width, the expected percentage decrease in accident frequency would be 1.27 percent and the 95 percent confidence interval would be from 0.61 to 1.92 percent. It should be noted that, while these percentage effects apply directly to accident frequencies, they also apply to accident rates per million entering vehicles, because the computation assumes that all other features of the intersection—including the major-road and crossroad ADTs—remain unchanged.

A positive sign for a coefficient in Table 11 indicates that accident frequency at an intersection increases as the median width increases. Conversely, a negative sign indicates that intersection accidents decrease as the median width increases.

Figures 17 through 19 show these results in the form of graphs of the relationship between predicted total multiple-vehicle accidents yearly and median width for "typical" intersections of each type. Each figure shows the intersection traffic volumes and the geometric and traffic control features that were assumed for that intersection type in preparing the figure. The major-road and crossroad ADTs chosen for each intersection type are approximately equal to the median ADTs for all intersections of that type. The geometric and traffic control features selected for the "typical" intersections are characteristic of most intersections of that type. The models presented previously predict the total number of multiple-vehicle accidents in a 3-year period. For convenience, Figures 17 through 19 show the results expressed as predicted multiple-vehicle accidents *per year.*

The plot for rural, four-leg, unsignalized intersections in Figure 17 makes clear that, regardless of the median width, this type of intersection experiences relatively few accidents: typically less than one multiple-vehicle accident per year. Nevertheless, median width can have a substantial effect on the accidents that do occur. Intersections with wide medians can experience

TABLE 11. Summary of median width effects from California accident analysis

	Median width effect expressed as a percentage of accident frequency					
	Per unit change of 1 m in median width			Per unit change of 1 ft in median width		
Intersection type	Estimate (%)	Lower confidence limit (%)	Upper confidence limit (%)	Estimate (%)	Lower confidence limit (%)	Upper confidence limit (%)
TOTAL MULTIPLE-VEHICLE ACCIDENTS						
Rural 4-leg unsignalized	-4.16	-6.30	-2.00	-1.22	-1.92	-9.61
Rural 3-leg unsignalized	--	--	--	--	--	--
Urban/suburban 4-leg unsignalized	5.67	4.23	7.08	1.73	1.29	2.16
Urban/suburban 3-leg unsignalized	2.69	1.11	4.26	0.82	0.34	1.30
Urban/suburban 4-leg signalized	3.02	1.11	4.97	0.92	0.34	1.50
FATAL AND INJURY MULTIPLE-VEHICLE ACCIDENTS						
Rural 4-leg unsignalized	-4.43	-7.15	-1.67	-1.35	-2.18	-0.51
Rural 3-leg unsignalized	--	--	--	--	--	--
Urban/suburban 4-leg unsignalized	5.25	3.21	7.31	1.60	0.98	2.23
Urban/suburban 3-leg unsignalized	--	--	--	--	--	--
Urban/suburban 4-leg signalized	2.92	1.11	4.72	0.89	0.34	1.44

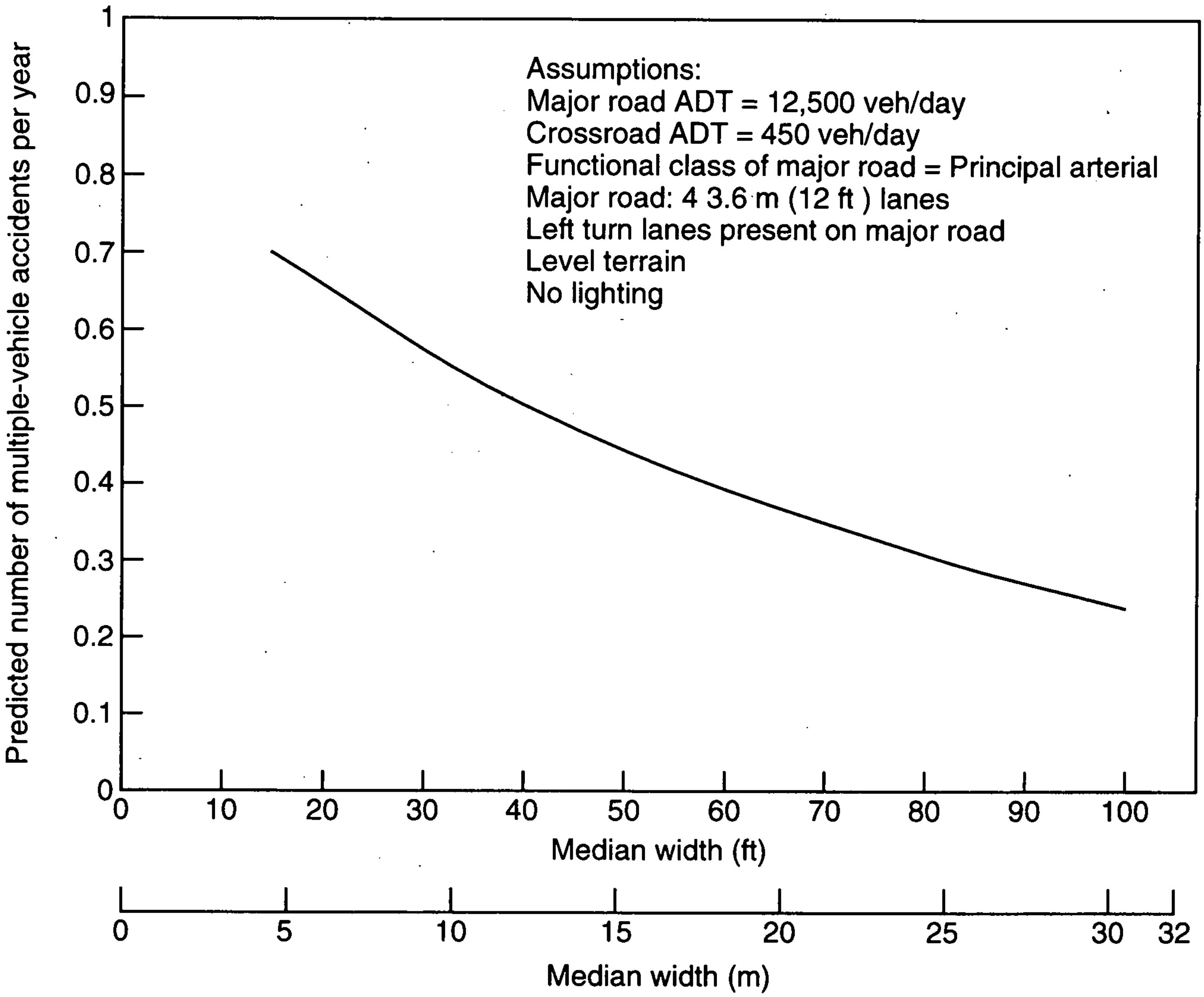


Figure 17. Predicted number of multiple-vehicle accidents per year as a function of median width for a typical rural four-leg unsignalized intersection.

less than half as many accidents as intersections with narrow medians.

At rural, three-leg, unsignalized intersections, median width has no statistically significant effect on accidents. It may be reasonable to assume that, because the design characteristics of rural, three-leg, and four-leg intersections are so similar, accident frequencies would decrease as median width increased at three-leg intersections, as well; however, the accident frequencies and rates for rural, three-leg intersections are so low and the effect of median width, if any, is so small that this hypothesis cannot be proven. Three-leg intersections have fewer conflict points than four-leg intersections and also tend to have lower crossroad traffic volumes than four-leg intersections.

Figure 18 shows the predicted accident experience as a function of median width for typical urban/suburban, unsignalized intersections. For both three-leg and four-leg intersections, multiple-vehicle accident frequency increases as median width increases. The figure shows, however, that four-leg intersections typically experience more multiple-vehicle accidents than three-leg intersections and the sensitivity of accidents to median width is greater for four-leg intersections than for three-leg intersections. The effect of median width on multiple-vehicle accidents at a typical urban/suburban, three-leg, unsignalized intersection, as illustrated in the figure, is so small that it may not need to be a major factor in design. However, it is apparent that for a four-leg intersection, a wider median can substantially increase multiple-vehicle accidents— this suggests that wider medians should be avoided at urban/suburban, four-leg, unsignalized intersections whenever possible.

Figure 19 shows the relationship between median width and multiple-vehicle accidents for a typical urban/suburban, four-leg, signalized intersection. As in the case of urban/suburban, four-leg, unsignalized intersections, multiple-vehicle accidents can increase substantially as median width increases, and it appears that wider medians should be avoided on divided highways with at-grade, signalized intersections in the urban/suburban setting.

There is a marked contrast between the effects of median

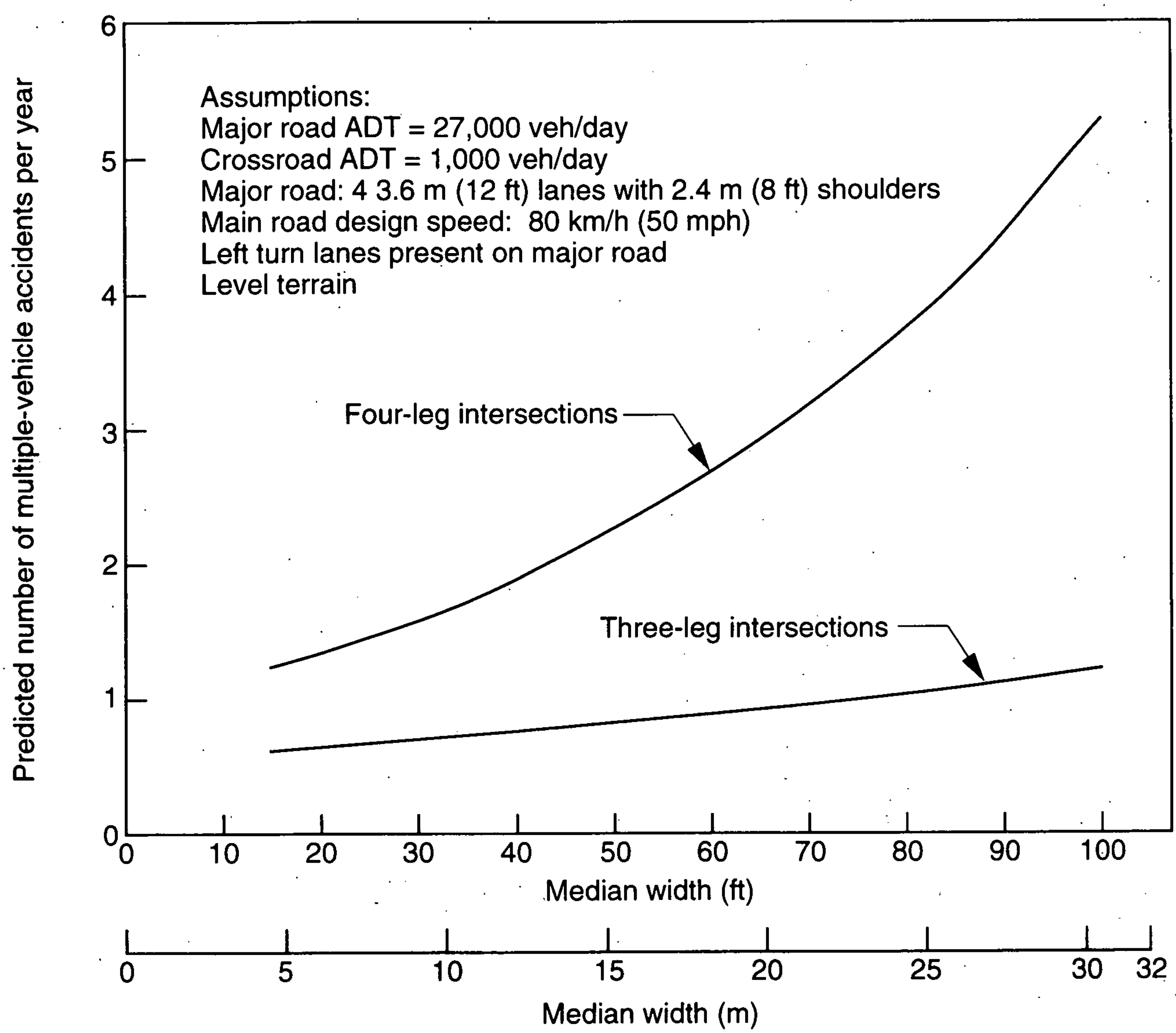


Figure 18. Predicted number of multiple-vehicle accidents per year as a function of median width for a typical urban/suburban unsignalized intersection.

width on accidents at divided highway intersections in urban/suburban and rural areas. In rural areas, multiple-vehicle accidents decrease as median width increases, while the opposite is true in urban/suburban areas.

Field Observational Studies

Field observational studies were conducted to observe driver behavior and any traffic operational or safety problems occurring at a selected sample of 40 intersections on divided highways. The sample included the following:

- Twenty rural, four-leg, unsignalized intersections with median widths ranging from 9 to 44 m (30 to 144 ft)
- Eight suburban, four-leg, unsignalized intersections with median widths ranging from 5 to 18 m (18 to 60 ft)
- Six suburban, four-leg, signalized intersections with median widths ranging from 5 to 63 m (16 to 207 ft)
- Six intersections with special features, including T-intersections, intersections with tapered and parallel offset left-turn lanes, and intersections with median acceleration lanes

These 40 study intersections were located in 10 states: California, Illinois, Iowa, Kansas, Maryland, Missouri, New Jersey, Pennsylvania, Texas, and West Virginia. Thus, the sample included sites in several major regions of the United States and had good geographic diversity. Table 12 summarizes the characteristics of the 40 study intersections.

The 20 rural, four-leg, unsignalized intersections, in particular, included various traffic control practices on the median roadway (i.e., at the intersection of the median roadway with the far roadway of the divided highway). Of these 20 intersections, 7

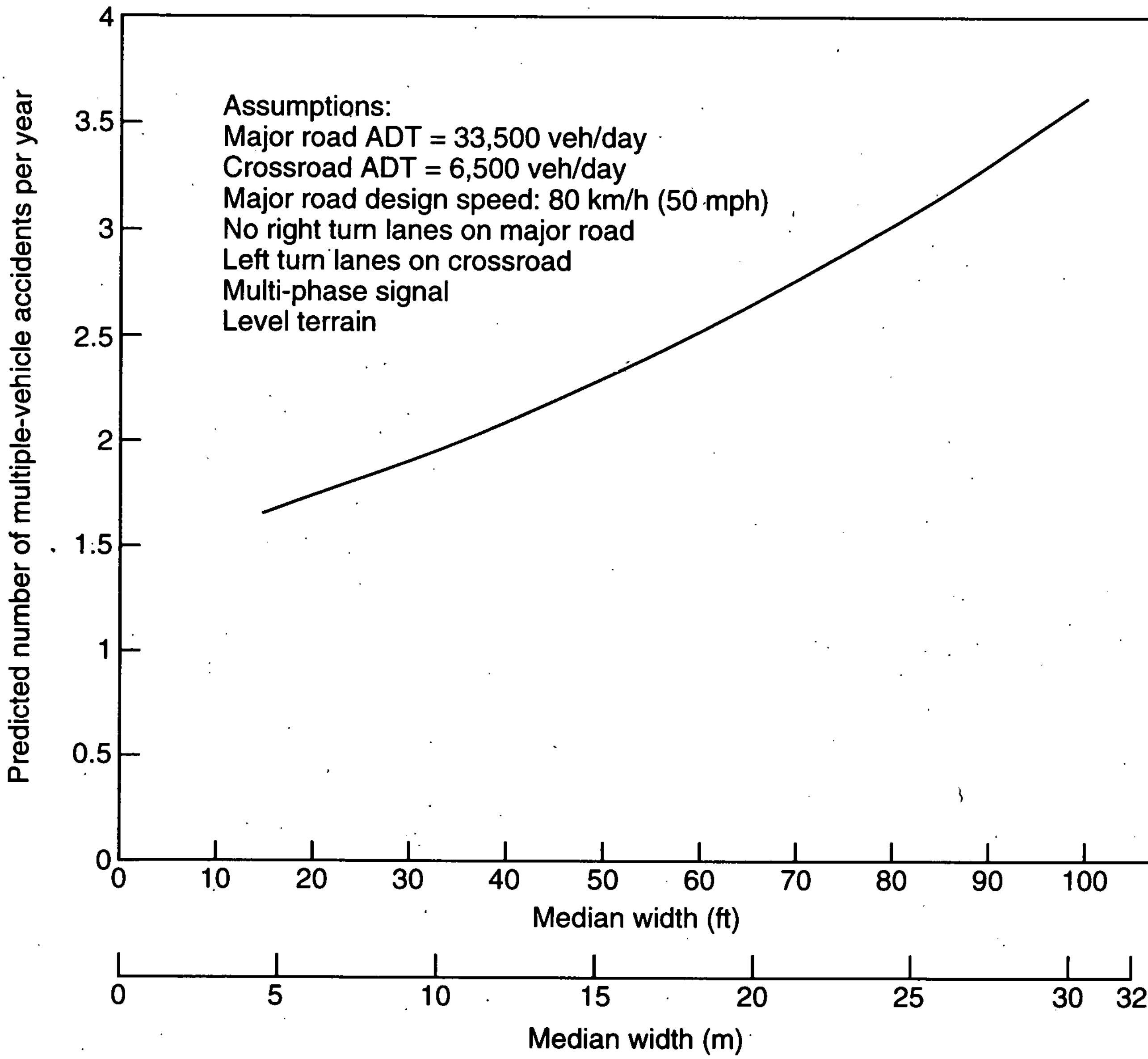


Figure 19. Predicted number of multiple-vehicle accidents per year as a function of median width for a typical urban/suburban signalized intersection.

had stop control, 7 had yield control, and 6 had no control on the median roadway.

Figure 20 presents photographs of several typical rural, unsignalized intersections with various median widths. Similar photographs for suburban, unsignalized and suburban, signalized intersections are presented in Figures 21 and 22, respectively.

Data Collection Periods

Field data were collected at each intersection for periods of up to 6 hr during daylight hours on weekdays. A total of approximately 200 hr of field data were collected at the 40 sites, or an average of 5 hr per site. At suburban intersections and at rural intersections likely to carry commuter traffic, the data collection period included either the morning or evening peak hour.

Data Collection Procedures

The field data were collected by videotaping traffic operations with two or more video cameras. The cameras were positioned to obtain different views of traffic operations on the median roadway. Figure 23 shows a typical setup for a data collection site. At some intersections, the video cameras were set up in adjacent quadrants on the same side of the divided highway as shown in the figure. At other intersections, camera locations on opposite sides of the divided highway were used. The camera

TABLE 12. Summary of field data collection sites

Site Number	Area Type	Traffic Control: Major Road	Traffic Control: Minor Road	Traffic Control: Median Rdwy	Median Width m (ft)	Median Opening m (ft)	Median Type	Number of Lanes on Each Approach: Major Road Thru	Major Road Left	Major Road Right	Crossroad Thru	Crossroad Left	Crossroad Right	Major Road Speed Limit km/h (mph)	Angle of Intersection	ADT (veh/day) Major Road	ADT (veh/day) Crossroad	Notes
RURAL UNSIGNALIZED INTERSECTIONS (20 intersections)																		
CA106	Rural	Unsignalized	STOP	No Control	14 (46)	17 (56)	D	2	1*	0	1	0	0	88 (55)	90	32000	13000	EB xroad leg is a driveway
CA107	Rural	Unsignalized	STOP	STOP	41 (134)	12 (40)	D	2	0	0	1	0	0	88 (55)	90	13000	1200	
CA108	Rural	Unsignalized	STOP	No Control	16 (52)	18 (60)	D	2	1	0	1	0	0	88 (55)	90	42500	600	
IA101	Rural	Unsignalized	STOP	STOP	34 (110)	9 (30)	D	2	0	0	1	0	0*	88 (55)	90	15000	13000	
IL105	Rural	Unsignalized	STOP	No Control	9 (30)	18 (58)	D	2	1	1*	1	0	0	88 (55)	90	8600	1500	
IL106	Rural	Unsignalized	STOP	YIELD	15 (48)	15 (50)	D	2	1	1	1	1	1	88 (55)	90	8200	900	
KS101	Rural	Unsignalized	STOP	YIELD	25 (82)	17 (56)	D	2	1	1	1	0	0	88 (55)	90	11000	1700	Flashing beacon
MD101	Rural	Unsignalized	STOP	YIELD	18 (60)	18 (58)	D	2	1	1	1	1*	0	88 (55)	90	16100	2100	Flashing beacon
MD102	Rural	Unsignalized	STOP	YIELD	23 (75)	16 (53)	D	2	1	1	1	0	0	88 (55)	90	19600	500	
MD103	Rural	Unsignalized	STOP	No Control	13 (44)	15 (50)	D	2	1	1	1	0	0	88 (55)	90	22600	2300	
MD104	Rural	Unsignalized	STOP	STOP	27 (90)	13 (43)	D	3	1	1	1	0	0	88 (55)	90	50300	800	
MO104	Rural	Unsignalized	STOP	STOP	26 (85)	9 (31)	D	2	0	0	1	0	0	88 (55)	90	10500	800	Flashing beacon
MO105	Rural	Unsignalized	STOP	STOP	12 (40)	19 (62)	D	2	0	0	1	0	0	88 (55)	90	10800	900	Flashing beacon
TX101	Rural	Unsignalized	STOP	YIELD	25 (82)	16 (51)	D	2	1	0	1	0	0	88 (55)	90	7400	500	
TX103	Rural	Unsignalized	STOP	YIELD	22 (73)	17 (56)	D	2	1	1*	1	0	0	88 (55)	30L*	17200	2100	Flashing beacon
TX104	Rural	Unsignalized	STOP	YIELD	21 (68)	18 (60)	D	2	1	0	1	0	1	88 (55)	45R/75R	9600	2700	Flashing beacon
TX105	Rural	Unsignalized	STOP	STOP	44 (144)	12 (39)	D	2	1*	1*	1	0	0	88 (55)	75R	22000	1200	Flashing beacon; one MAL
TX106	Rural	Unsignalized	STOP	STOP	29 (96)	16 (54)	D	2*	1	0	1	0	0	88 (55)	90	14800	4000	
WV101	Rural	Unsignalized	STOP	No Control	12 (40)	21 (68)	D	2	1	1*	1	0	0	88 (55)	90	11000	1200	
WV103	Rural	Unsignalized	STOP	No Control	12 (40)	24 (80)	D	2	1	1	1	0	0	88 (55)	90	17500	4200	Flashing beacon
SUBURBAN UNSIGNALIZED INTERSECTIONS (8 intersections)																		
CA102	Suburban	Unsignalized	STOP	No Control	16 (54)	19 (62)	R	2	1	1	1	0	0	88 (55)	90	30900	700	MAL (one dirn only)
CA103	Suburban	Unsignalized	STOP	No Control	10 (33)	21 (70)	D	2	0	1*	1	0	0	80 (50)	90	26100	2000	
CA105	Suburban	Unsignalized	STOP	No Control	8 (26)	19 (62)	R	2	1	0	1	0	0	88 (55)	90	13600	2100	
IL104	Suburban	Unsignalized	STOP	YIELD	12 (40)	21 (68)	D	2	1	1	1	0	0	88 (55)	75R	17800	1300	
MO101	Suburban	Unsignalized	STOP	YIELD	18 (60)	9 (28)	D	2	1	0	1	0	0	88 (55)	90	23000	1900	
MO102	Suburban	Unsignalized	STOP	YIELD	18 (60)	9 (28)	D	2	1	0	1	0	0	88 (55)	90	21400	1100	
NJ101	Suburban	Unsignalized	STOP	YIELD	12 (38)	19 (61)	R	2	1	1	1	0	0	80 (50)	90	38600	300	Truck speed limit: 45 mph
WV102	Suburban	Unsignalized	STOP	No Control	5 (18)	35 (116)	R	2	1	1*	1	0	0	88 (55)	90	12000	2200	
SUBURBAN SIGNALIZED INTERSECTIONS (6 intersections)																		
KS102	Suburban	Signalized	Signalized	–	11 (35)	29 (96)	D	2	1	1	1	0	1	88 (55)	90	9000	2500	
MO103	Suburban	Signalized	Signalized	–	5 (16)	32 (104)	R	2	1	1	1	1	1	72 (45)	90	45600	5400	
PA101	Suburban	Signalized	Signalized	–	6 (20)	41 (134)	R	2	1	1	1	0	1*	88 (55)	75R	49700	6000	
TX102	Suburban**	Signalized	Signalized	–	23 (77)	18 (59)	D	2	1	0	1	0	1*	88 (55)	75R	9300	3000	
TX107	Suburban	Signalized	Signalized	–	63 (207)	13 (44)	R	3	0	0	2/1	0	0	72 (45)	90	36000	10500	
TX108	Suburban	Signalized	Signalized	–	63 (205)	9 (31)	D	3	0	0	2	0	0	88 (55)	90	37780	4900	
INTERSECTIONS WITH SPECIAL FEATURES (6 intersections)																		
CA101	Rural	Unsignalized	STOP	No Control	22 (72)	15 (50)	D	2	1	1	1	1	1	88 (55)	90	18800	2200	MAL
CA104	Rural	Unsignalized	STOP	No Control	11 (36)	28 (92)	D	2	1*	1*	1	0	0	88 (55)	90	72000	300	T-intersection; MAL
IL101	Suburban	Signalized	Signalized	–	20 (65)	15 (50)	R	2	1	0	1	0	0	80 (50)	90	13500	3200	TOLTL
IL102	Suburban	Signalized	Signalized	–	14 (46)	22 (73)	D	2	1	1	2	1	1	80 (50)	90	20600	10500	TOLTL
IL103	Suburban	Signalized	Signalized		9 (29)	23 (75)	R	2	1	1	2	1	1	64 (40)	90	21400	23900	POLTL
WV104	Rural	Unsignalized	STOP	No Control	12 (40)	13 (42)	D	2	1*	0	1	0	0	88 (55)	90	7800	3500	T-intersection

* Applies to one approach only; no comparable lane or skew angle on opposite approach.
** This intersection is actually in a rural area, but operates much like a suburban intersection.

Abbreviations:
MAL = Median acceleration lane
POLTL = Parallel offset left-turn lane
TOLTL = Tapered offset left-turn lane

Median Type:
D = Depressed
R = Raised

Direction of Skew Angle:
L = Left forward
R = Right forward

locations depended primarily on local terrain; elevated camera positions were selected, whenever possible, to obtain the best view of the intersection.

Observers at the intersections kept a log of maneuvers of interest during the study period. This log was used during the data reduction effort. At some sites, the logs were particularly valuable in determining whether a vehicle in the median roadway encroached on the through lanes of the divided highway, because that was sometimes difficult to judge from the video image alone.

Night Studies

Studies were also performed at three sites to observe whether drivers operated at night in accordance with the designer's intentions. The three sites included one rural, unsignalized intersection with a particularly wide median (41 m or 134 ft); one rural, unsignalized intersection with median acceleration lanes; and one suburban, signalized intersection with tapered offset left-turn lanes. During each night study, an observer made a count of turning movement volumes through the median roadway while noting any erratic maneuvers or other evidence of driver confusion. No videotaping was performed at night because of low ambient-light levels.

Data Reduction

Data reduction of the field observational data consisted of two stages: (1) turning-movement counts from the videotapes recorded in the field and (2) classification of maneuvers observed on the videotapes.

The data reduction effort revealed that 348,788 vehicles entered and passed through the study intersections during the study period. Trucks constituted 8.8 percent of these vehicles. A key volume variable in the data analysis is the median volume, which is the total volume passing through the median roadway and is the sum of the volumes for eight individual movements:

- Two major-road left-turn movements
- Two major-road U-turn movements
- Two crossroad through movements
- Two crossroad left-turn movements

The total median volume observed during the study period was 46,460 vehicles (or 13.3 percent of the total entering volume). In contrast, through vehicles on the major road constituted 78.7 percent of the traffic entering the intersections. More detailed summaries of the traffic volume counts at the study intersections are presented in Appendix B.

The videotapes were reviewed to characterize driver behavior at the intersections and to evaluate any operational problems that occurred. Every vehicle that passed through the median area, defined as the median roadway plus the major-road left-turn lanes (see Figure 3), was observed on the videotape. Data on driver behavior were recorded for the vehicles involved in each maneuver during which one or more of the following events occurred:

1. Two or more vehicles were present in the median area at

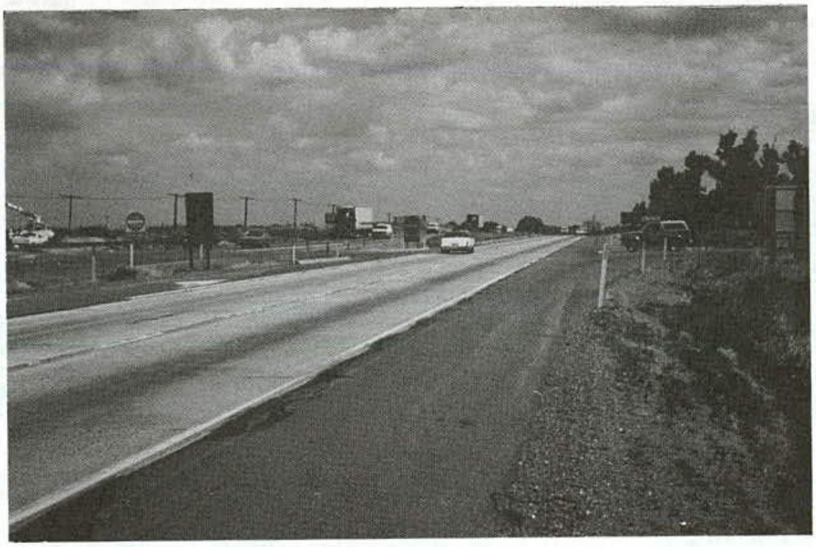
9-m (30-ft) median width

12-m (40-ft) median width

13-m (44-ft) median width

Figure 20. Photographs of typical rural unsignalized intersections on divided highways.

16-m (52-ft) median width



41-m (134-ft) median width

Figure 20. Photographs of typical rural unsignalized intersections on divided highways (continued).

the same time (whether moving or stopped) for unsignalized intersections *or* two or more vehicles were stopped on the median roadway at the same time for signalized intersections.

2. One or more stopped vehicles encroached on the through lanes of the divided highway.
3. There was evident hesitation or confusion by one or more drivers.
4. Any other unusual or noteworthy traffic event was observed.

Any undesirable driving behavior in the median roadway was noted for each observed maneuver. Examples of undesirable driving behavior that were observed include the following:

- Side-by-side queuing of vehicles in the median roadway
- Stopping by vehicles in the median roadway at an angle other than perpendicular to the major road
- Stopping by vehicles in the median roadway in such a position that they encroached on the through lanes of the major road

For each observed maneuver, it was noted whether any traffic conflict (i.e., braking or swerving by one or more vehicles) resulted that could be associated with some risk of a traffic accident. For left-turn maneuvers by opposing vehicles, it was also noted whether the vehicles turned left in front of or behind one another.

Using a procedure, described in Appendix B, the maneuver data were analyzed as interactions between pairs of vehicles present on the roadway simultaneously. Interactions between pairs of vehicles in the median area were classified on the basis of the following four factors:

- Approach by which the first vehicle of the pair entered the intersection:

5-m (18-ft) median width

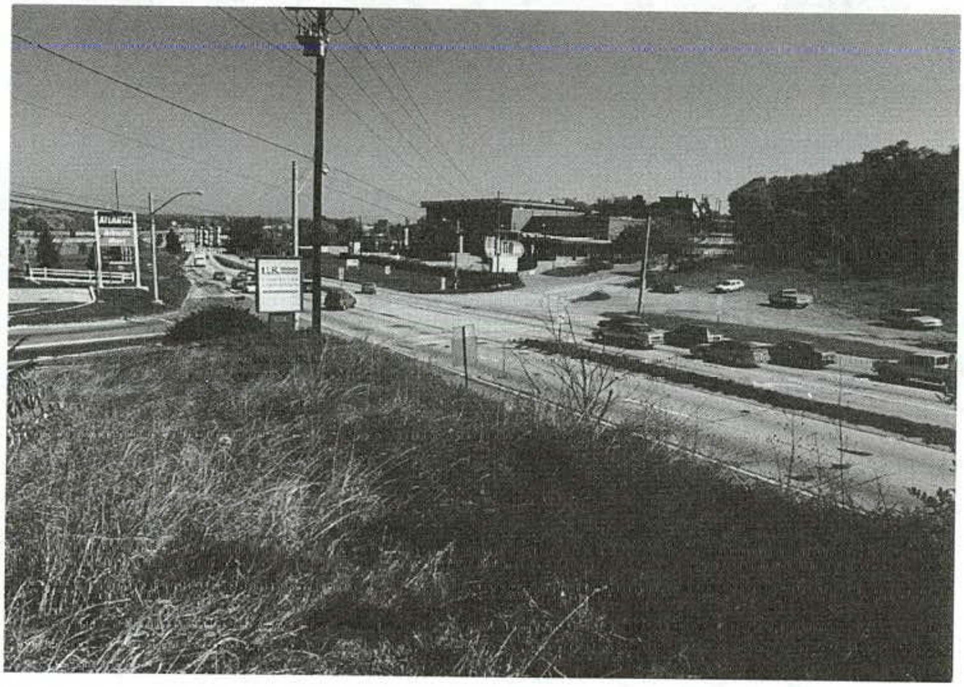
16-m (54-ft) median width

Figure 21. Photographs of typical suburban unsignalized intersections on divided highways.

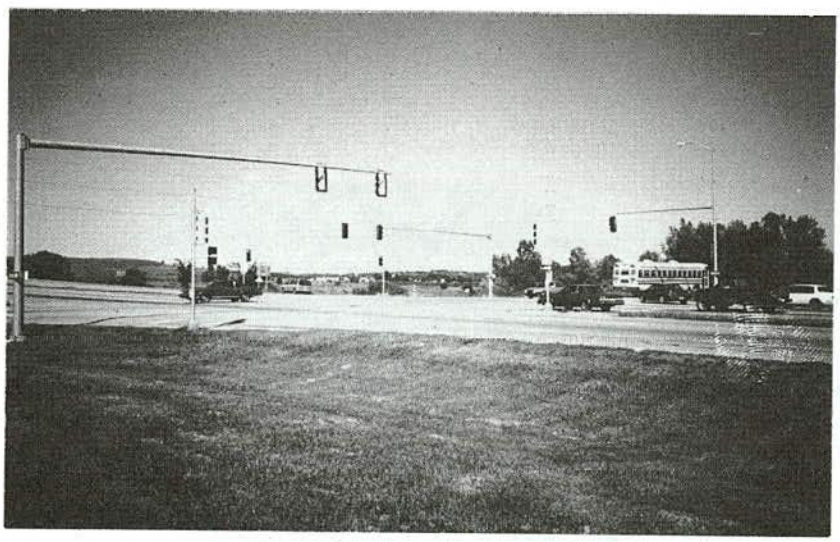
—Major road (J)
—Minor road or crossroad (N)

- Maneuver made by the first vehicle:
  —Through movement (T)
  —Left turn (L)
  —U-turn (U)

- Approach by which the second vehicle of the pair entered the intersection:
  —From the same approach as the first vehicle (S)
  —From the approach opposite to the first vehicle (O)
  —From the approach to the right of the first vehicle (R)
  —From the approach to the left of the first vehicle (L)



6-m (20-ft) median width



11-m (35-ft) median width

Figure 22. Photographs of typical suburban signalized intersections on divided highways.

- Maneuver made by the second vehicle:
  - —Through movement (T)
  - —Left turn (L)
  - —U-turn (U)

Right-turn maneuvers were not considered because the classification of interactions between vehicles extended only to vehicles that passed through the median area.

If each of the four approaches to a four-leg intersection is analyzed separately, a total of 64 combinations of these factors are found; however, 32 of these combinations are mirror images of the other 32, in which the first of the interacting vehicles come

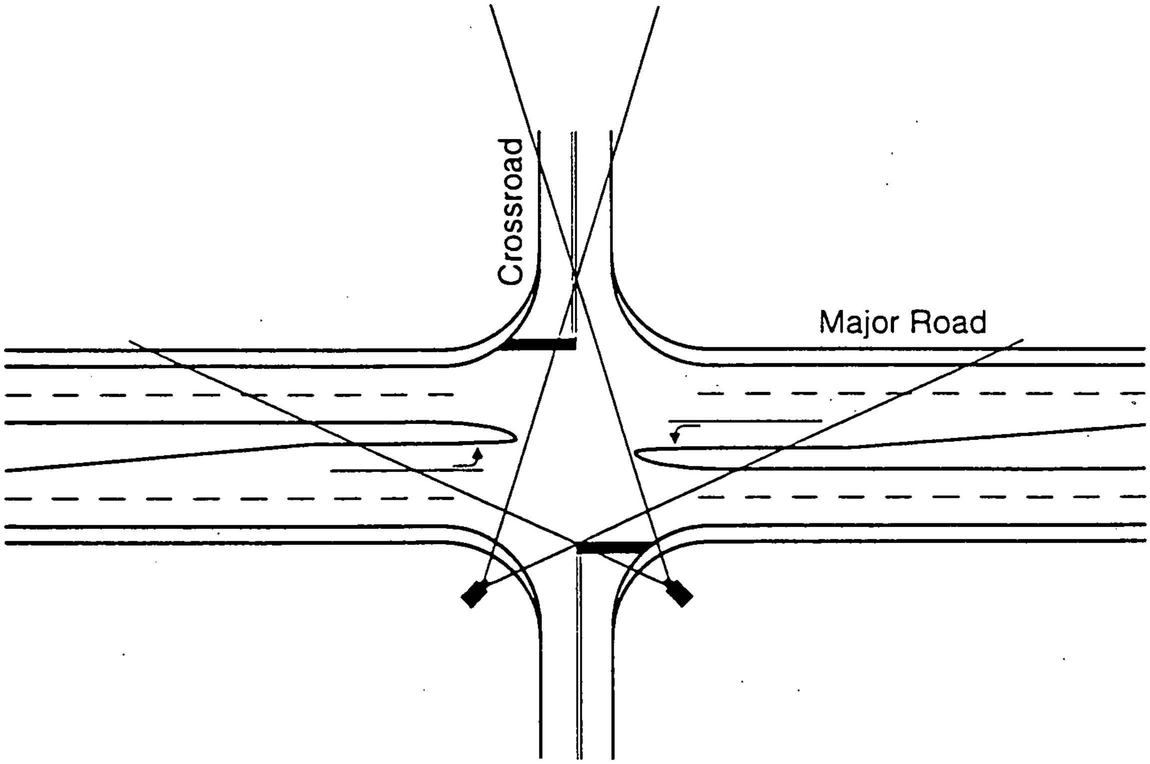


Figure 23. Typical data collection setup using video cameras.

from opposite approaches. If these mirror-image maneuvers are combined, there are a total of 32 unique combinations of maneuvers by two consecutive vehicles passing through the median. Figure 24 identifies these combinations of maneuvers. Each maneuver combination is identified by a four-character code, representing the four descriptors of the maneuver combination listed above. For example, a maneuver combination in which the first vehicle approached the intersection on the major road (J) and turned left (L), while the second vehicle approached from the crossroad approach to the left of the first vehicle (L) and made a through movement on the crossroad (T), would be classified as maneuver code JLLT.

Each of these 32 possible combinations of maneuvers was observed at least once in the field observational studies. Table 13 summarizes the frequencies of each of these maneuver combinations for all 40 sites as a whole. The table shows that 6,680 maneuver combinations were observed. It also shows that certain maneuver combinations were quite common (e.g., maneuver codes JLOL, JLSL, NLLL, NLRL, and NLSL), while other maneuver combinations (typically those involving U-turn maneuvers) were quite rare. Tables in Appendix B break down these maneuver data by site and study period.

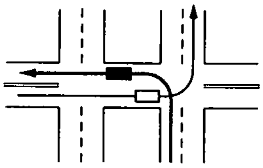
In addition to the two-vehicle interactions in the median roadway described above, operational problems related to traffic conflicts between vehicles leaving the median roadway and through vehicles on the major road were also noted, as were single-vehicle erratic maneuvers in which driver confusion or misunderstanding of the intersection geometrics was evident.

Data Analyses

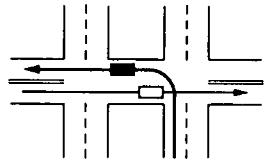
An analysis of the field observational data was conducted to determine what traffic operational problems were observed and whether these problems were related to the median width or the geometric design of the median roadway. The issues that were examined included turn-in-front/turn-behind behavior in opposing left turns, types of undesirable driving behavior observed at divided highway intersections, and the effects of median width and median opening length on the frequency of undesirable driving behavior. The results of these analyses are presented below. The field observational data were also used to evaluate driver compliance with traffic control devices; the results of this analysis are presented in the subsequent section on traffic control at divided highway intersections.

Turn-in-Front/Turn-Behind Behavior

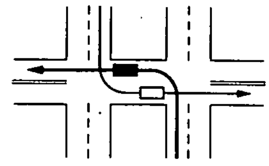
One issue of interest to the research was how drivers making opposing left turns are influenced by the median width. Specifically, it was hypothesized that, at intersections with narrow medians, drivers making opposing left turns tend to turn in front of one another and, at intersections with wide medians, drivers making opposing left turns turn behind one another. These two types of turning behavior are illustrated in Figure 25. However, 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.



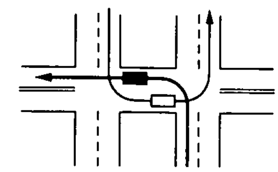
JLLL–Major-road left turn/crossroad left turn from left approach.



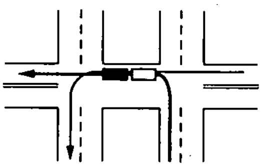
JLLT–Major-road left turn/crossroad through movement from left approach.



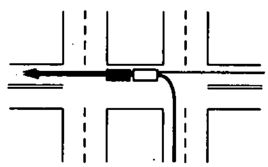
JLOL–Major-road left turn/major-road through movement from opposite approach.



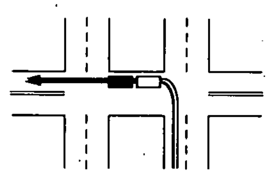
JLOU–Major-road left turn/major-road U-turn from opposite approach.



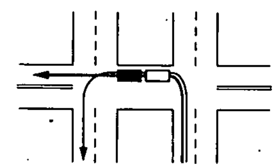
JLRL–Major-road left turn/crossroad from right approach.



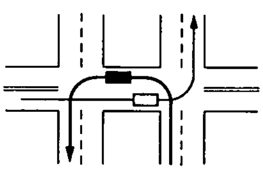
JLRT–Major-road left turn/crossroad through movement from right approach.



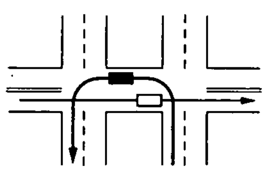
JLSL–Major-road left turn/major-road left turn from same approach.



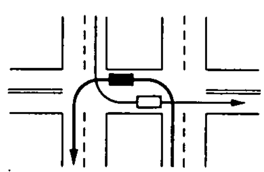
JLSU–Major-road left turn/major-road U-turn from same approach.



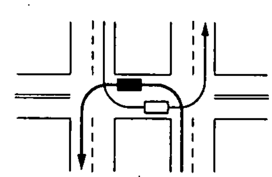
JULL–Major-road U- turn/crossroad left turn from left approach.



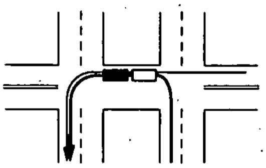
JULT–Major-road U-turn/crossroad through movement from left approach.



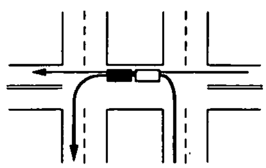
JUOL–Major-road U-turn/major-road left turn from opposite approach.



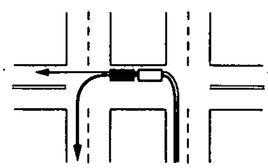
JUOU–Major-road U-turn/major-road U-turn from opposite approach.



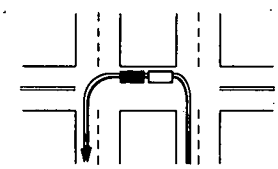
JURL–Major-road U-turn/crossroad left turn from right approach.



JURT–Major-road U-turn/crossroad through movement from right approach.



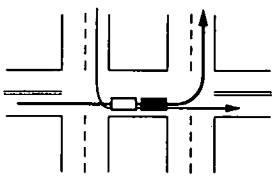
JUSL–Major-road U-turn/major-road left turn from same approach.



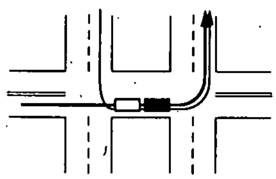
JUSU–Major-road U-turn/major road U-turn from same approach.

Figure 24. Two-vehicle maneuver combinations on the median roadway of divided highway intersections.

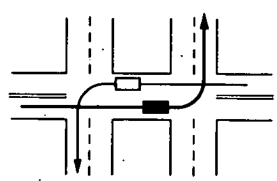
An analysis for rural, unsignalized intersections (provided in Appendix B) found that at intersections with median widths of less than 15 m (50 ft), vehicles making opposing left turns tend to turn in front of one another. In contrast, at intersections with median widths of more than 15 m (50 ft), vehicles making opposing left turns tend to turn behind one another. Only about 10 percent of opposing left-turn vehicles at intersections with median widths of less than 15 m (50 ft) turned behind one



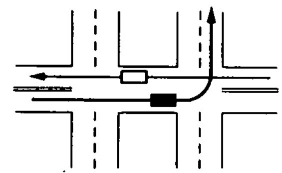
NLLL– Crossroad left turn/major-road left turn from left approach.



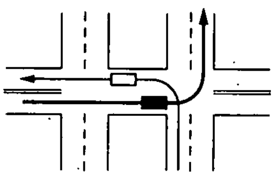
NLLU– Crossroad left turn/major-road U-turn from left approach.



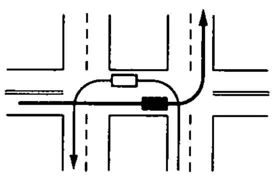
NLOL– Crossroad left turn/crossroad left turn from opposite approach.



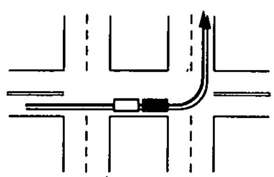
NLOT– Crossroad left turn/crossroad through movement from opposite approach.



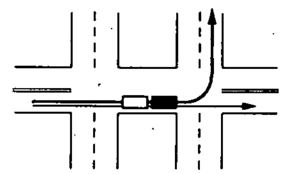
NLRL– Crossroad left turn/major-road left turn from right approach.



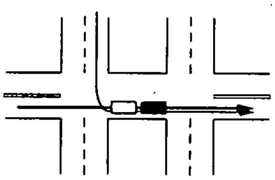
NLRU– Crossroad left turn/major-road U-turn from right approach.



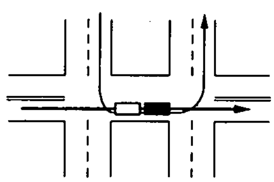
NLSL– Crossroad left turn/crossroad left turn from same approach.



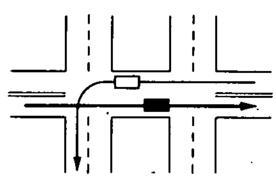
NLST– Crossroad left turn/crossroad through movement from same approach.



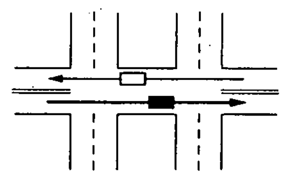
NTLL– Crossroad through movement/major-road left turn from left approach.



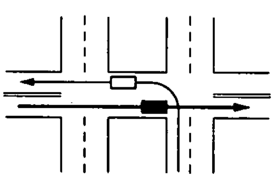
NTLU– Crossroad through movement/major-road U-turn from left approach.



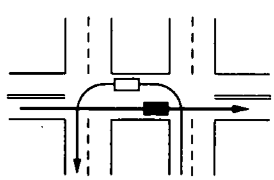
NTOL– Crossroad through movement/crossroad left turn from opposite approach.



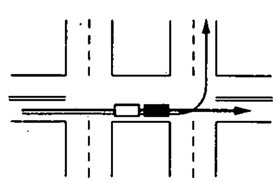
NTOT– Crossroad through movement/crossroad through movement from opposite approach.



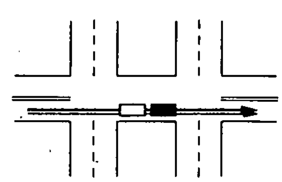
NTRL– Crossroad through movement/major-road left turn from right approach.



NTRU– Crossroad through movement/major-road U-turn from right approach.



NTSL– Crossroad through movement/crossroad left turn from same approach.



NTST– Crossroad through movement/crossroad through movement from same approach.

Figure 24. Two-vehicle maneuver combinations on the median roadway of divided highway intersections (continued).

TABLE 13. Summary of frequencies of maneuver combinations for all fixed sites combined

Maneuver code	Number (percent) of maneuvers observed	
JLLL	217	(3.2)
JLLT	108	(1.6)
JLOL	978	(14.6)
JLOU	104	(1.6)
JLRL	187	(2.8)
JLRT	108	(1.6)
JLSL	1,720	(25.7)
JLSU	98	(1.5)
JULL	29	(0.4)
JULT	1	(0.0)
JUOL	108	(1.6)
JUOU	22	(0.3)
JURL	49	(0.7)
JURT	8	(0.1)
JUSL	99	(1.5)
JUSU	31	(0.5)
NLLL	414	(6.2)
NLLU	77	(1.2
NLOL	125	(1.9)
NLOT	96	(1.4)
NLRL	628	(9.4)
NLRU	34	(0.5)
NLSL	559	(8.4)
NLST	145	(2.2)
NTLL	94	(1.4)
NTLU	6	(0.1)
NTOL	55	(0.8)
NTOT	70	(1.0)
NTRL	251	(3.8)
NTRU	7	(0.1)
NTSL	148	(2.2)
NTST	104	(1.6)
	6,680	

another, and no opposing left-turn vehicles were observed to turn in front of one another at intersections with median widths greater than 15 m (50 ft). This analysis was based primarily on left turns by opposing major-road vehicles (maneuver type JLOL); however, opposing left turns by crossroad vehicles (maneuver type NLOL), while fewer in number, showed similar behavior.

A similar pattern was found for suburban, unsignalized intersections with median widths of less than 15 m (50 ft): nearly all the opposing left turns involved vehicles turning in front of one another. Unlike the rural, signalized intersections, at the two suburban, unsignalized intersections with 18-m (60-ft) median widths at which opposing left turns were observed, opposing left-turn drivers also displayed turn-in-front, rather than turn-behind behavior. However, both of the intersections with wider medians where turn-in-front behavior was observed had small channelizing islands between the left-turn lanes and the major road; this design guided drivers into the median roadway at an angle and encouraged opposing left-turn drivers to turn in front of each another. Thus, there were no suburban, unsignalized intersections without channelizing islands 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.

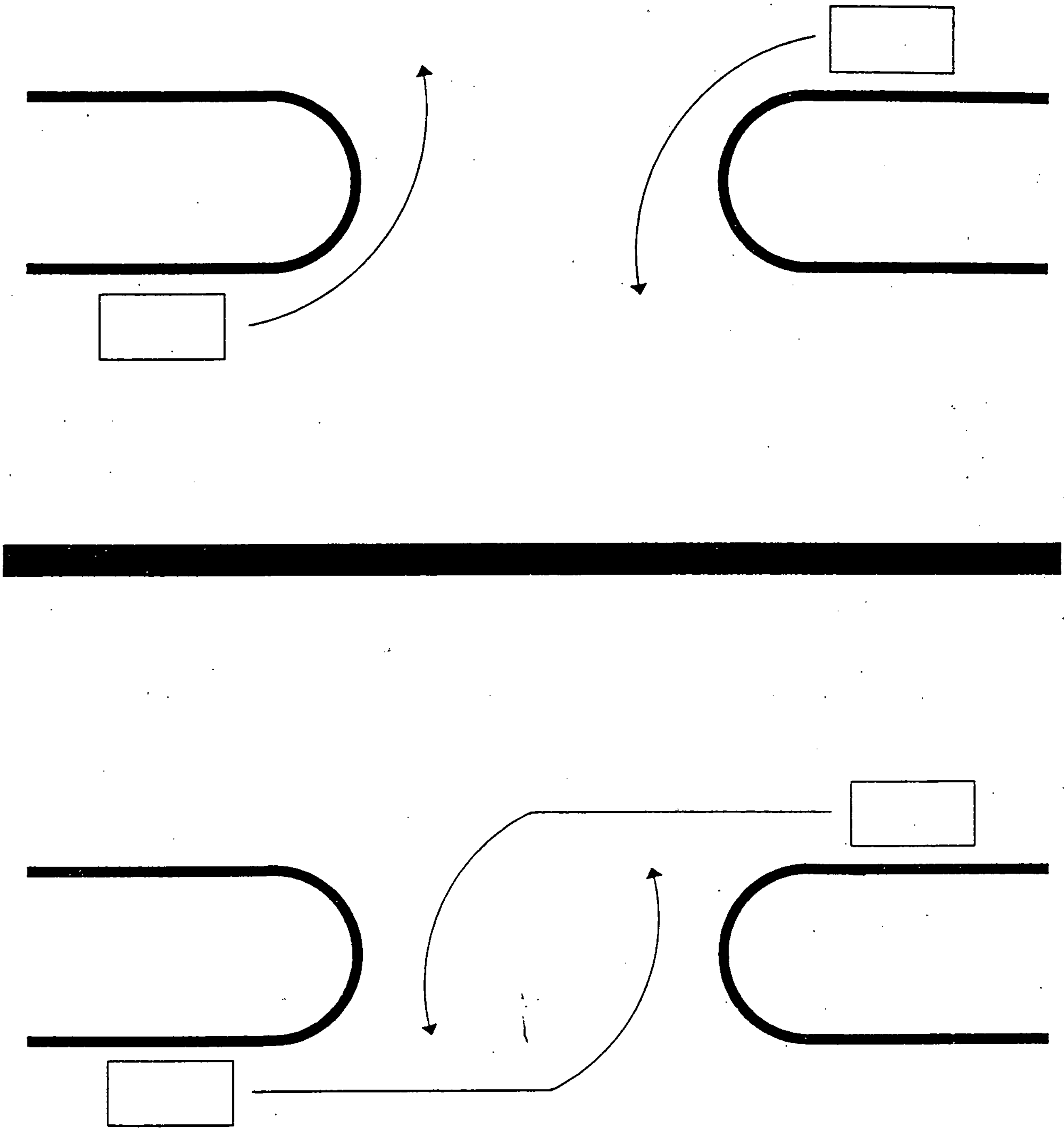


Figure 25. Alternative paths for left-turning vehicles: turning in front of one another and turning behind one another.

In summary, the data for the rural, unsignalized intersections demonstrate that, for median widths of up to 15 m (50 ft), opposing left-turn drivers tend to turn in front of one another, and at intersections with median widths of more than 15 m (50 ft), opposing left-turn drivers tend to turn behind one another. There is no implication that turn-in-front behavior is either more or less desirable than turn-behind behavior; indeed, each type of turning behavior generally appears appropriate for the range of median widths under which it is observed. However, the field data do suggest that driver behavior at a median width of approximately 15 m (50 ft) changes in that drivers making opposing left turns at narrower medians tend to turn in front of each another, and drivers at wider medians tend to turn behind each another. That finding may make 15 m (50 ft) an appropriate breakpoint in setting design polices for selecting median widths.

The findings concerning turn-in-front/turn-behind behavior at rural intersections could be only partially verified at suburban intersections, but it is reasonable to assume that the turning behavior at intersections with wider medians is the same in suburban areas as in rural areas. It is possible that turn-behind

behavior could result in undesirable operations at some higher volume urban or suburban intersections because it could lead to gridlock; however, that was not observed in any of the field studies conducted.

Observed Types of Undesirable Driving Behavior on the Median Roadway

As explained above, vehicles turning in front of each another or behind each another do not necessarily show undesirable driving behavior. However, several types of driving behavior were observed at the field study intersections that clearly were undesirable. Those types of undesirable driving behavior include the following:

- Side-by-side queuing on the median roadway by vehicles in the same travel direction
- Stopping at an angle on the median roadway
- Encroaching on a through lane of the divided highway

These three types of undesirable behavior are illustrated by the drawings in Figure 26 and by the photographs in Figures 27, 28, and 29, respectively.

When one vehicle is waiting on the median roadway for an opportunity to cross or enter the far roadway of a divided highway and a second vehicle arrives in the same travel direction, the most desirable traffic operations result when the second vehicle stops behind the first. However, in some cases, the second driver may stop his or her vehicle beside rather than behind the first vehicle. This 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 potential conflicts. Side-by-side queuing tends to occur in the following situations:

1. Where the median width is less than the length of two vehicles, it is most desirable that a second vehicle not enter the median roadway if a first vehicle traveling in the same direction is already there. It would be most desirable for the driver of the second vehicle to wait before crossing the near lanes of the major road or wait in the major-road left-turn lane (if one is provided) until sufficient space on the median roadway is available. However, if the second vehicle enters such a narrow median, the driver may find a choice between pulling alongside the first vehicle, stopping in the median at an unusual angle, or encroaching on the through lanes of the major road. In this situation, the driver of the second vehicle may choose to stop beside the first vehicle as the best of several undesirable choices.

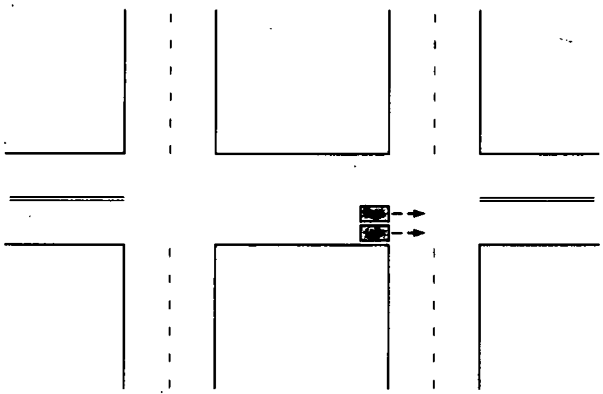
2. Where the median opening is sufficiently long, even if the median is wide enough to store two or more vehicles one behind the another, the driver of a second vehicle may be tempted to pull beside the first vehicle to avoid delay. For example, if the first vehicle is waiting in the median to turn left onto the major road, a second vehicle intending to cross the major road may pull beside the first vehicle. As long as the crossing vehicle stops to the right of the turning vehicle, this maneuver may be executed safely, but there is always the potential for the drivers to become confused about which vehicle is making which maneuver and about which vehicle is going to proceed first. In some cases, the side-by-side queuing may involve two drivers making the same maneuver; the second driver considers the first driver too timid and doesn't wait for the first driver to accept a gap in traffic and complete his or her maneuver. In this situation, there is a concern that, as the median opening becomes longer, more drivers may be tempted to queue side by side.

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 may find it necessary to stop at an angle to avoid encroaching on the through lanes of the major road or to avoid blocking another vehicle. 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. In contrast, when a vehicle on the median roadway stops perpendicular to the through lanes of the major road, with its turn signal activated (where appropriate), other drivers are not likely to be confused about the intended path of that vehicle.

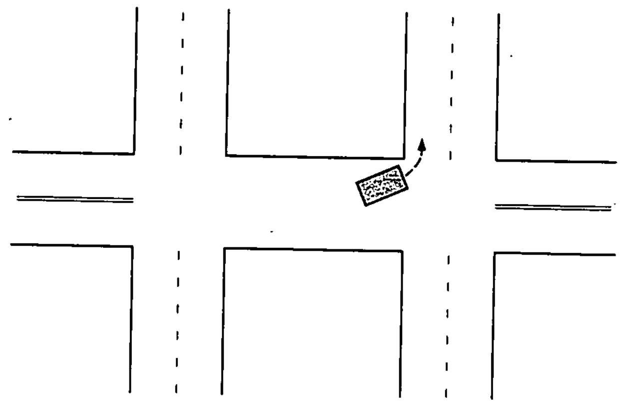
Finally, a vehicle on the median roadway may be stopped with the front or rear of the vehicle encroaching on a through lane of the divided highway. This maneuver occurs occasionally when a vehicle on the median roadway misjudges the edge of the through travel lanes or stops after failing to see an oncoming through vehicle; in this case, the front of the driver's vehicle encroaches on the through lanes of the far roadway of the divided highway. A more common situation occurs when a driver enters the median roadway when it is already occupied by one or more other vehicles. At times, the driver of the vehicle entering the median roadway may stop with the rear of his or her vehicle encroaching on a through lane of the near roadway of the divided highway. Some drivers entering the median roadway may choose to encroach on a through lane, rather than queue in a side-by-side position or stop at an angle; this maneuver can occur particularly if the driver perceives (correctly or incorrectly) that he or she will have to encroach on a through lane for only a short interval or that no potentially conflicting through vehicles will be present on the major road. Finally, 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.

Each of the types of undesirable driving behavior described above—side-by-side queuing, angle stopping, and encroaching on a through lane of the divided highway—could be prevented if drivers did not enter the median area unless they were sure their vehicles had enough room and if, once they entered the median, they stopped behind the other vehicle(s) traveling in the same direction. However, human nature being what it is, some undesirable driving behavior of this type is bound to occur.

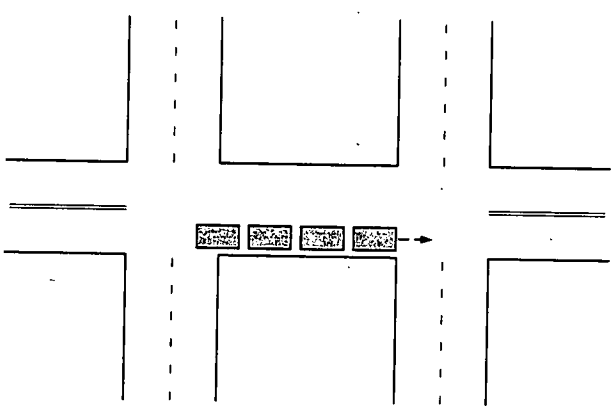
Table 14 summarizes the frequency of the three observed types of undesirable driving behavior for specific intersection types and ranges of median width. More detailed tables in Appendix B present a breakdown of these data by study period for individual sites. Table 14 includes instances of undesirable driving behavior for all maneuvers in which two (or more) vehicles were in the median roadway at the same time. It should be noted that the frequencies of the individual types of undesirable driving behavior in the table do not necessarily add to the total



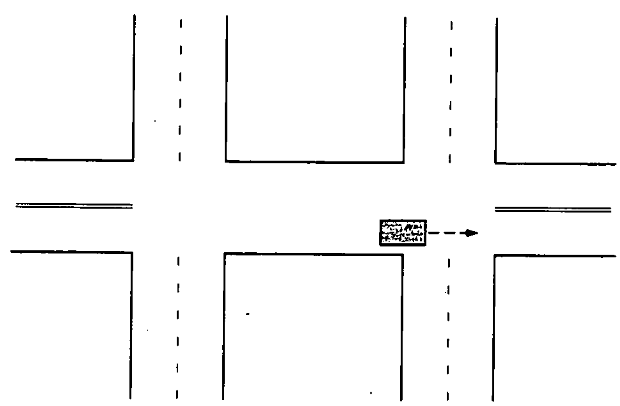
Side-by-side queuing



Angle stopping



Encroachment on through lanes



Encroachment on through lanes

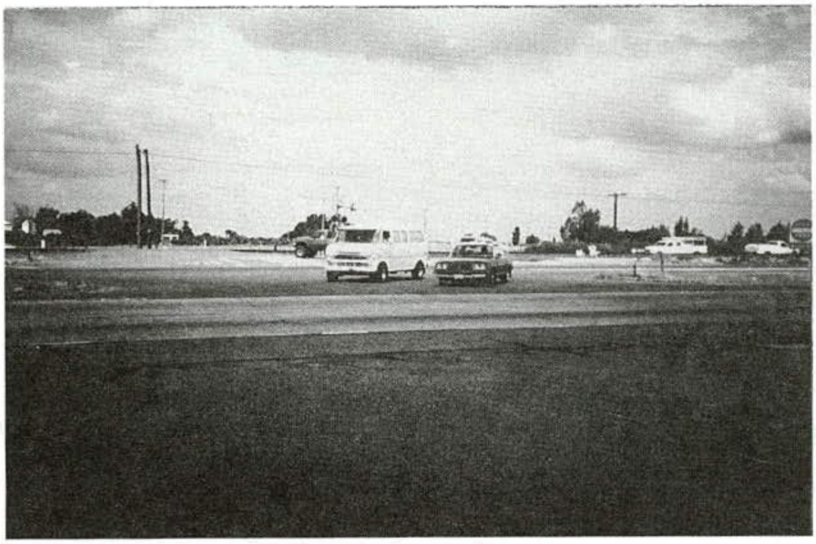
Figure 26. Types of undesirable driving behavior on the median roadway of divided highway intersections.

frequency of undesirable driving behavior, because some maneuvers showed more than one type of undesirable driving behavior (e.g., both side-by-side queuing and angle stopping or both angle stopping and encroaching on a through lane). The rate measure used for undesirable driving behavior is the rate of maneuvers involving such behavior per 1,000 vehicles passing through the median roadway.

The instances of undesirable driving behavior summarized in Table 14 include behavior for some vehicle pairs in which the first vehicle of the pair entered the median when other vehicles were already there. To best determine the effect of particular median geometrics on undesirable driving behavior, researchers decided to focus on those two-vehicle median-roadway maneuver pairs in which no other vehicles were in the median when the first vehicle of the pair entered it. Table 15 is analogous to Table 14 but includes only those maneuvers showing undesirable driving behavior with no other vehicles in the median. The columns headed Vehicle 1 include all maneuvers in which the first vehicle of the pair entered the unoccupied median area and showed some type of undesirable behavior. The columns headed Vehicle 2 include maneuvers in which the first vehicle of the pair entered the median roadway without any undesirable behavior, but the second vehicle of the pair—often because of the presence of the first vehicle—did show some type of undesirable behavior.

An analysis was conducted of the maneuver types for which one or more types of undesirable driving behavior were observed. It was found that 64 percent of the undesirable maneu-

side-by-side queuing



Side-by-side queuing and angle stopping

Figure 27. Photographs of side-by-side queuing on the median roadway.

vers involved vehicles traveling in the same direction through the median roadway, while only 36 percent involved vehicles traveling in the opposite direction. This suggests that the most common source of undesirable driving behavior on the median roadway appears to be competition for space between vehicles traveling in the same direction through the median.

Median Width and Median Opening Length Effects

An analysis was conducted to determine the effect of the geometrics (size and shape) of the median roadway on the types of undesirable maneuvers observed above. The key descriptors

Figure 28. Photograph of angle stopping on the median roadway.

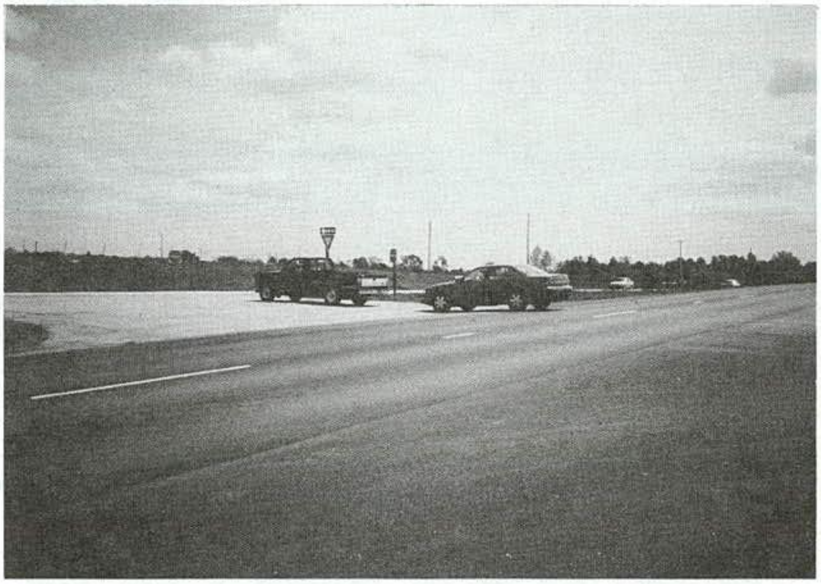


Figure 29. Photograph of a vehicle on the median roadway encroaching on the through lanes of the divided highway.

of the median roadway that were considered included the median width and the median opening length. Other descriptors of the median roadway were also examined, including its area (the product of the median width and median opening length) and its shape (the ratio of the median width and median opening length), but these measures did not prove to be as useful as the median width and median opening length.

Tables 16 and 17 summarize the results of an analysis of the correlations between the median width, median opening length, and the rate of undesirable maneuvers per 1,000 vehicles entering the median roadway (based on the data shown in Table B-9 in Appendix B by site and study period for unsignalized intersections). The measures of correlation shown in the table are the Pearson correlation coefficients. The Pearson correlation coefficient is a measure of the linear association between two variables and varies in value from 0.0 (representing no statistical association between the two variables) to 1.0 (representing perfect association between the two variables). The sign of the Pearson correlation coefficient represents the sense of the relationship between the two variables. A positive correlation coefficient means that as one variable increases in value, so does the other; a negative correlation coefficient indicates that as one variable increases in value, the other decreases in value.

TABLE 14. Frequency and rate of undesirable driving behavior for all pairs of vehicles using the median roadway at the same time (tabulated by site)

Site Number	Total Vehicle Pairs Observed in Median	Type of Undesirable Driving Behavior: Side-by-Side Queuing	Angle Stopping	Encroachment on Major Road	Total Frequency Undesirable Maneuvers	Median Volume (vehs)	Rate of Undesirable Maneuvers (per 1000 vehs)
RURAL UNSIGNALIZED INTERSECTIONS							
CA106	14	0	13	1	13	68	191.2
CA107	69	0	0	0	0	316	0.0
CA108	54	18	47	1	51	311	164.0
IA101	N/A	0	2	1	3	407	7.4
IL105	12	2	5	1	5	534	9.4
IL106	37	0	8	1	9	522	17.2
KS101	311	22	87	0	100	1065	93.9
MD101	118	25	37	4	53	509	104.1
MD102	28	5	5	0	7	188	37.2
MD103	92	16	16	0	30	571	52.5
MD104	215	1	35	9	44	508	86.6
MO104	75	0	1	0	1	662	1.5
MO105	31	0	23	0	23	363	63.4
TX101	14	0	3	0	3	204	14.7
TX103	143	10	92	0	95	844	112.6
TX104	666	186	479	7	519	1426	364.0
TX105	130	6	1	0	7	523	13.4
TX106	646	48	336	7	355	1417	250.5
WV101	99	2	46	0	47	807	58.2
WV103	219	4	131	1	132	898	147.0
Subtotal	2973	345	1367	33	1497	12143	123.3
SUBURBAN UNSIGNALIZED INTERSECTIONS							
CA102	64	1	36	1	36	315	114.3
CA103	117	4	61	4	62	693	89.5
CA105	62	2	13	2	15	951	15.8
IL104	91	1	35	0	36	517	69.6
MO101	227	12	100	0	109	828	131.6
MO102	393	8	262	0	263	894	294.2
NJ101	5	0	4	0	4	106	37.7
WV102	141	0	0	0	0	990	0.0
Subtotal	1100	28	511	7	525	5294	99.2
SUBURBAN SIGNALIZED INTERSECTIONS							
KS102	6	0	0	0	0	1416	0.0
MO103	5	0	0	0	0	3388	0.0
PA101	5	0	0	2	2	1091	1.8
TX102	0	0	0	0	0	976	0.0
TX107	964	0	5	52	55	5020	11.0
TX108	1278	0	0	14	14	2863	4.9
Subtotal	2258	0	5	68	71	14754	4.8
INTERSECTIONS WITH SPECIAL FEATURES							
CA101	125	2	34	2	37	1274	29.0
CA104	33	0	9	2	11	250	44.0
IL101	6	0	0	0	0	1620	0.0
IL102	16	0	0	0	0	3383	0.0
IL103	28	0	0	0	0	7030	0.0
WV104	141	1	95	1	95	712	133.4
Subtotal	349	3	138	5	143	14269	10.0
TOTAL	6680	376	2021	113	2236	46460	48.1

NOTE: Observed maneuver frequencies of specific types of undesirable driving behavior do not always add to the total frequencies because some maneuvers exhibited more than one type of undesirable driving behavior.

TABLE 15. Frequency and rate of undesirable driving behavior for two-vehicle maneuver pairs with no other vehicles present in the median area (summary by site)

		Type of Undesirable Driving Behavior by Vehicle 1			Type of Undesirable Driving Behavior by Vehicle 2					
Site Number	Total Maneuvers in Median	Side-by-Side Queuing	Angle Stopping	Encroachment on Major Road	Side-by-Side Queuing	Angle Stopping	Encroachment on Major Road	Total Frequency of Undesirable Maneuvers	Median Volume (vehs)	Rate of Undesirable Maneuvers (per 1000 vehs)
RURAL UNSIGNALIZED INTERSECTIONS										
CA106	6	0	5	0	0	0	0	5	68	73.5
CA107	60	0	0	0	0	0	0	0	316	0.0
CA108	51	0	35	0	5	10	1	48	311	154.3
IA101	N/A	0	0	0	0	0	0	0	407	0.0
IL105	11	0	3	0	2	2	1	5	534	9.4
IL106	34	0	4	1	0	3	0	8	522	15.3
KS101	245	0	34	0	15	39	0	84	1065	78.9
MD101	95	0	22	0	13	10	3	44	509	86.4
MD102	23	0	2	0	1	1	0	3	188	16.0
MD103	77	5	10	0	8	4	0	27	571	47.3
MD104	169	0	0	7	1	24	2	33	508	65.0
MO104	59	0	0	0	0	1	0	1	662	1.5
MO105	29	0	15	0	0	6	0	21	363	57.9
TX101	43	0	16	0	0	8	0	24	567	42.3
TX103	120	0	63	0	5	11	0	77	844	91.2
TX104	392	0	176	0	37	86	4	281	1426	197.1
TX105	95	0	1	0	2	0	0	3	523	5.7
TX106	431	0	137	0	12	77	1	223	1417	157.4
WV101	89	0	31	0	0	11	0	42	807	52.0
WV103	154	0	89	0	1	14	0	103	898	114.7
Subtotal	2183	5	643	8	102	307	12	1032	12506	82.5
SUBURBAN UNSIGNALIZED INTERSECTIONS										
CA102	53	0	26	0	0	5	0	31	315	98.4
CA103	97	0	41	0	0	10	1	52	693	75.0
CA105	61	0	11	0	0	2	1	14	951	14.7
IL104	69	0	20	0	1	5	0	26	517	50.3
MO101	173	2	40	0	4	39	0	83	828	100.2
MO102	257	0	140	0	1	30	0	171	894	191.3
NJ101	5	0	3	0	0	1	0	4	106	37.7
WV102	116	0	0	0	0	0	0	0	990	0.0
Subtotal	831	2	281	0	6	92	2	381	5294	72.0
SUBURBAN SIGNALIZED INTERSECTIONS										
KS102	5	0	0	0	0	0	0	0	1416	0.0
MO103	5	0	0	0	0	0	0	0	3388	0.0
PA101	5	0	0	0	0	0	2	2	1091	1.8
TX102	0	0	0	0	0	0	0	0	976	0.0
TX107	870	0	0	17	0	3	8	28	5020	5.6
TX108	1212	0	0	0	0	0	2	2	2863	0.7
Subtotal	2097	0	0	17	0	3	12	32	14754	2.2
INTERSECTIONS WITH SPECIAL FEATURES										
CA101	117	0	26	0	1	5	1	33	1274	25.9
CA104	32	0	7	1	0	2	1	11	250	44.0
IL101	6	0	0	0	0	0	0	0	1620	0.0
IL102	16	0	0	0	0	0	0	0	3383	0.0
IL103	28	0	0	0	0	0	0	0	7030	0.0
WV104	111	0	66	0	0	10	0	76	712	106.7
Subtotal	310	0	99	1	1	17	2	120	14269	8.4
TOTAL	5421	7	1023	26	109	419	28	1565	46823	33.4

NOTE: Observed maneuver frequencies of specific types of undesirable driving behavior do not always add to the total frequencies because some maneuvers exhibited more than one type of undesirable driving behavior.

Rural, Unsignalized Intersections: Table 16 shows that, at rural, unsignalized intersections, the rate of undesirable maneuvers decreases as the median width increases. This suggests that as the median of a rural divided highway becomes wider, fewer problems are observed at the intersections; however, this correlation is quite weak and is only barely significant at the 90 percent confidence level. Table B-9 in Appendix B shows that the predominant type of undesirable maneuver at rural unsignalized intersections is angle stopping, with a much lower frequency of side-by-side queuing, and very little encroaching on the through lanes.

In contrast, the table shows that the observed rate of undesirable maneuvers increases as the median opening length increases. The correlation coefficient for this relationship is highly significant. The median opening length at a divided highway intersection is largely dictated by the crossroad width and the design vehicle selected for left-turn maneuvers; however, these findings suggest that, within these constraints, the median opening should not be made unnecessarily wide.

A review of scatter plots of the data (shown in Figures B-7 and B-8 in Appendix B) suggest that the primary reason for the negative correlation between undesirable maneuvers and median

TABLE 16. Correlation between median roadway geometrics and rate of undesirable maneuvers for rural unsignalized intersections

Geometric variable	Correlation with rate of undesirable maneuvers[a]	Statistically significant[b]	Significance level	Sample size[c]
Median width	−0.230	YES[d]	0.095	54
Median opening length	+0.503	YES	0.001	54
Median area	+0.131	NO	0.346	54
Slenderness ratio	−0.393	YES	0.003	54

[a] Rate of undesirable maneuvers per 1,000 vehicles entering the median roadway as given in Table B-9.
[b] Statistically significant at 95% confidence level unless otherwise indicated.
[c] Number of study periods included in the analysis. Each study period is typically 2 hr in length at a particular intersection.
[d] Statistically significant at 90% confidence level.

TABLE 17. Correlation between median roadway geometrics and rate of undesirable maneuvers for suburban unsignalized intersections

Geometric variable	Correlation with rate of undesirable maneuvers[a]	Statistically significant[b]	Significance level	Sample size[c]
Median width	+0.790	YES	0.001	21
Median opening length	−0.718	YES	0.003	21
Median area	−0.065	NO	0.781	21
Slenderness ratio	+0.744	YES	0.001	21

[a] Rate of undesirable maneuvers per 1,000 vehicles entering the median roadway as given in Table B-9.
[b] Statistically significant at 95% confidence level unless otherwise indicated.
[c] Number of study periods included in the analysis. Each study period is typically 2 hr in length at a particular intersection.

width is that almost no undesirable maneuvers occur at medians more than 31 m (100 ft) wide.

Suburban, Unsignalized Intersections: Table 17 shows, for suburban, unsignalized intersections, the opposite relationship exists between the rate of undesirable maneuvers and the median roadway geometrics from that found at rural, unsignalized intersections. A positive correlation exists between the rate of undesirable maneuvers and median width, and a negative correlation exists between the rate of undesirable maneuvers and median opening length. Although the correlations found are based on a relatively small sample size (traffic observational data for 21 2-hr study periods at eight intersections), they are highly significant in statistical terms. As was the case at the rural, unsignalized intersections, the predominant undesirable maneuver observed at the suburban, unsignalized intersections was angle stopping.

The findings for suburban, unsignalized intersections indicate that medians should not be unnecessarily wide because the rate of observed problems appears to increase with the median width. On the other hand, median openings that are longer than necessary do not appear to be the concern in suburban areas that they are in rural areas.

Accident Analysis of Field Study Sites

An analysis of the accident data for the field study sites found no correlation between the intersection accident rates and either median width or median opening length; however, given the high variability of accident data and the small number of intersections available for analysis—20 rural, unsignalized intersections and 8 suburban, unsignalized intersections—it was expected that no statistically significant correlations would be found.

Rural Intersections with Wide Medians

One concern underlying this research was that intersections with wide medians could be confusing to drivers and, thus, might cause many accidents. In fact, far from confusing drivers, the three rural, unsignalized intersections with medians more than 31 m (100 ft) wide had some of the lowest rates of undesirable driving behavior in the field observational studies. All three of these sites had both a relatively wide median and a relatively short median opening length. In all three cases, the median opening length was 12 m (40 ft) or less; in one case, the median opening length was only 9 m (30 ft). This design makes the median roadway appear to drivers as part of the two-lane crossroad extended across the median. In fact, such median roadways are typically marked with a double yellow centerline. The centerline and the relatively narrow shoulder area on the median roadway help to remove the temptation for drivers to cut across the median and stop at an angle when turning left or to queue side by side in the median. In other words, the geometrics and pavement markings create the impression that there is not much choice in traversing the intersection except to follow the path that the designer intended. In addition, the wide median provides enough space to store a variety of vehicle combinations conventionally (i.e., one behind the other), minimizing the motivation for side-by-side queuing.

Summary of Traffic Safety and Operational Effects

In summary, relationships were found between median width and the safety performance of divided highway intersections, and these findings are supported by two independent analyses. Both the accident analysis of the California data base and the field observational studies suggest that, at rural, unsignalized intersections, the frequency of accidents and undesirable driving behavior decreases as the median width increases. At suburban, unsignalized intersections, the opposite result was observed—indicating that the frequency of traffic accidents and instances of undesirable driving behavior increases as the median width increases. Traffic accidents also increase with median width at suburban, signalized intersections.

There is no obvious explanation for the different effects of median width at rural and suburban, unsignalized intersections. However, these findings appear to be well founded empirically because they are supported by both the accident studies and the field observational studies. Possible explanations for this effect were examined, but none was conclusive. Specifically, while the average median volume for rural, unsignalized intersections is lower than for suburban, unsignalized intersections, the range of median volumes at rural, unsignalized intersections completely overlaps the range of median volumes at suburban, unsignalized intersections; thus, it does not appear that differences in traffic volumes on the median roadway explain the differences in the observed effects. Suburban, unsignalized intersections tend to have lower ratios of crossroad to major-road ADT than rural, unsignalized intersections, because the major-road through volumes are relatively high. No one factor appears to account for the observed differences. Instead, the observed differences are probably a combination of differences in many factors between rural and suburban intersections, including major-road through volumes; trip length; daily, weekly, and monthly traffic volume variations; and driver expectancy.

The effect of median opening length on intersection operations could only be evaluated from the field observational study data, because median opening lengths were not available for the intersections in the California accident data base. However, on the basis of the analysis of the field observational data, it appears that the effect of median opening length is opposite to that of median width; i.e., the frequency of undesirable driving behavior increases with median opening length for rural, unsignalized intersections and decreases with median opening length for suburban intersections.

The findings on opposite effect of median opening length found at rural and suburban, unsignalized intersections are less well supported than the related findings on median width, because the findings on median opening length are based solely on the field observational studies and could not be evaluated in an accident study. The authors are very comfortable with the findings that short median openings are desirable at rural, unsignalized intersections, because of the findings of the field observational studies at rural intersections with wide medians discussed above. The implication that, by contrast, longer median openings are desirable at suburban intersections seems less well supported, however, because of the potential for side-by-side queuing; therefore, they have chosen not to base any policy recommendations on that finding.

TRAFFIC CONTROL AT DIVIDED HIGHWAY INTERSECTIONS

Current policies concerning traffic control devices, including signs, signals, and markings, are presented in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*24*). Little literature exists on the effectiveness of different traffic control device schemes for divided highway intersections.

Unsignalized Intersections

Current Traffic Control Policies

The MUTCD presents three signing plans that are applicable to divided highway intersections:

1. MUTCD Figure 2-3 (presented here as Figure 30) has Stop signs on the median roadway and is applicable to divided highway medians more than 9 m (30 ft) wide.
2. The lower portion of MUTCD Figure 2-3a (presented here as the lower portion of Figure 31) shows an alternative configuration to Figure 2-3 with Yield signs on the median roadway.
3. The upper portion of MUTCD Figure 2-3a (presented here as the upper portion of Figure 31) shows no Stop or Yield signs in the median and is applicable to divided highways with median widths of less than 9 m (30 ft).

The MUTCD gives very specific guidance on the use and placement of all these signs in Section 2A-31, Wrong-Way Traffic Control. The MUTCD states the following:

> Where roadways are separated by median widths of 30 ft or more, the intersections with the crossroad shall be signed as two separate intersections and One Way signs (Section 2B-29) should

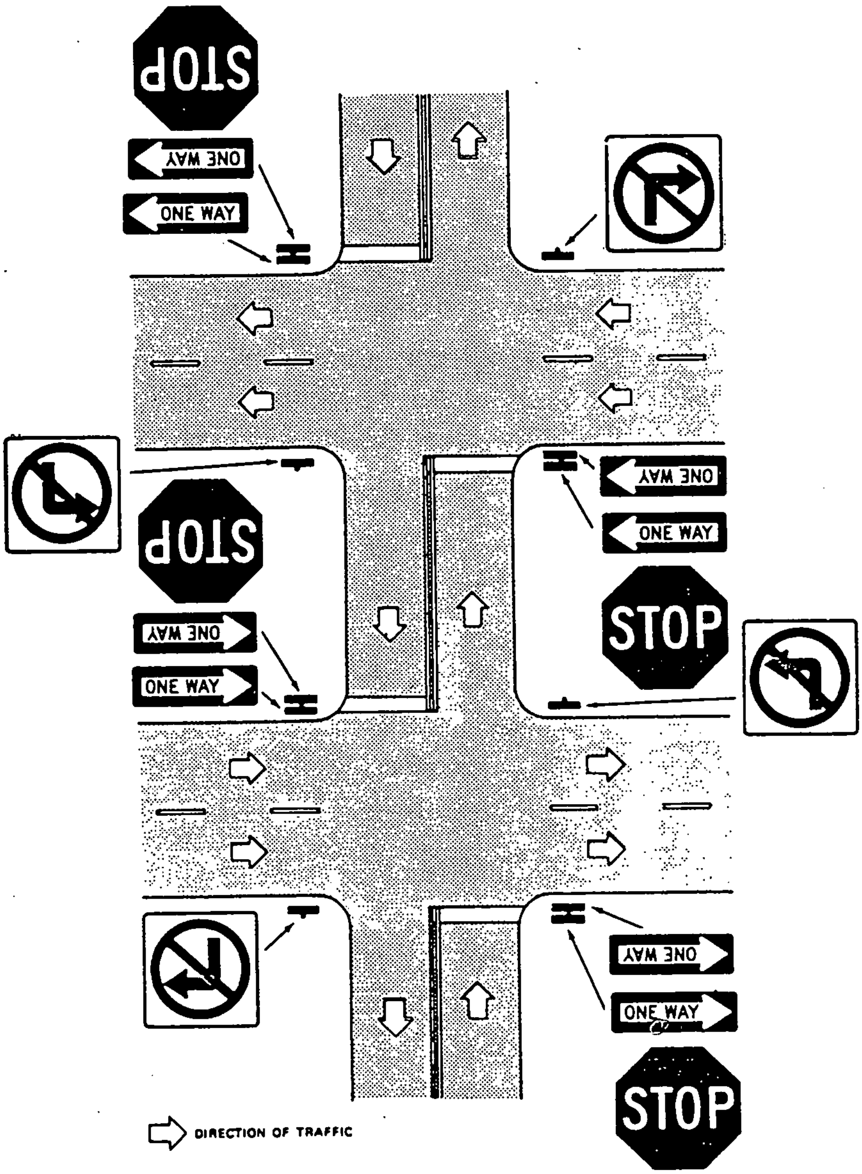


Figure 30. Locations of One-Way and turn prohibition signs at divided highway intersections (28).

be visible to each crossroad approach on the near right-hand and far left-hand corners of each intersection with the directional roadways as shown in Figure 2-3. However, when an engineering study has demonstrated that placement of One Way signs in the median area may create confusion, the near right-hand signs in the median may be omitted and One Way placed in the far-right quadrant of the intersection. Figure 2-3a shows this alternate scheme with one pair of One Way signs in the median replaced by Yield signs. Turn prohibition, Do Not Enter and Wrong Way signs may be used to supplement One Way sign layouts in Figures 2-3, 2-3a, or 2-4 [NOTE: MUTCD Figure 2-4 does not relate to intersections on divided highways].

One Way signs are not ordinarily needed at divided highway intersections with median widths of less than 30 ft. In cases where they are needed, combinations of One Way and/or Divided Highway Crossing, Do Not Enter, or Wrong Way signs may be used to improve operations at these intersections.

If used, Do Not Enter and Wrong Way signs should be placed on a divided highway at a location to be directly in view of a driver making a wrong-way entry from the crossroad. Additional signs may be placed where the median width is 30 ft or more (*28*).

As median widths increase to the point that the intersection functions more like two separate, closely spaced intersections, drivers of larger vehicles may be tempted to enter the median area between the two intersections, even if there is not enough room in the median area to store their vehicles. That may occur because the median roadway appears similar to a small "street" between the two intersections, which may suggest to some drivers that the median is wide enough to accommodate larger vehicles. Additional signing and pavement markings could add to this problem. As with the case described above, the MUTCD will allow "street-like" traffic control when medians are wider

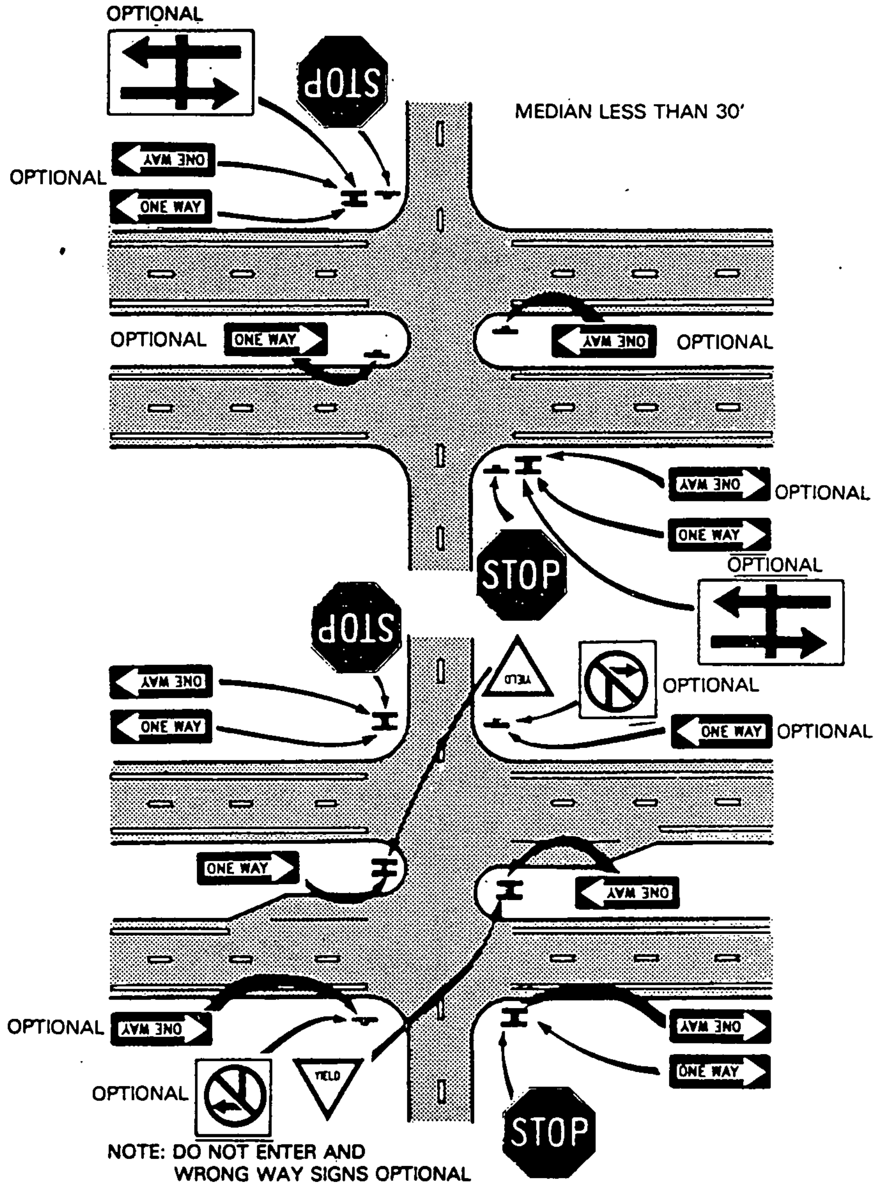


Figure 31. Alternative One-Way signing for divided highway intersections (28).

than 9 m (30 ft). However, a 9-m (30-ft) median provides only enough storage space for one or two passenger cars, and a larger design vehicle (e.g., WB-50) could not be stored in a 9-m (30-ft) median without encroaching on the opposing lanes.

The MUTCD does not distinguish clearly between the applicability of the upper and lower portions of Figure 2-3a. The upper portion of the figure is labeled as applicable to "medians less than 30′." The lower portion of the figure is not labeled with a specific median width range, which might lead one to suppose that it is also applicable to narrow medians; however, both the text quoted above and the equivalent figure in the 1978 edition of the MUTCD (*29*) make it clear that the lower portion of Figure 2-3a is applicable to medians more than 9 m (30 ft) wide.

The reason for the choice of 9 m (30 ft) as the threshold median width above which separate yield or stop control is provided for both intersections between the minor road and the divided highways is not stated in this MUTCD. It seems likely that this value is based on the operating experience of highway agencies rather than any particular piece of research.

Current highway agency practice appears to be to use no control on the median roadway for intersections with medians less than 9 m (30 ft) wide and to use stop control for medians more than 25 m (82 ft) wide. However, stop control, yield control, and no control are each used by some highway agencies on the median roadway of intersections with median widths in the range of 9 to 25 m (30 to 82 ft).

The signing at a divided highway intersection has two clear functions:

- To establish the right of way for vehicles crossing or turning onto each roadway
- To inform drivers on the crossroad approaches that they

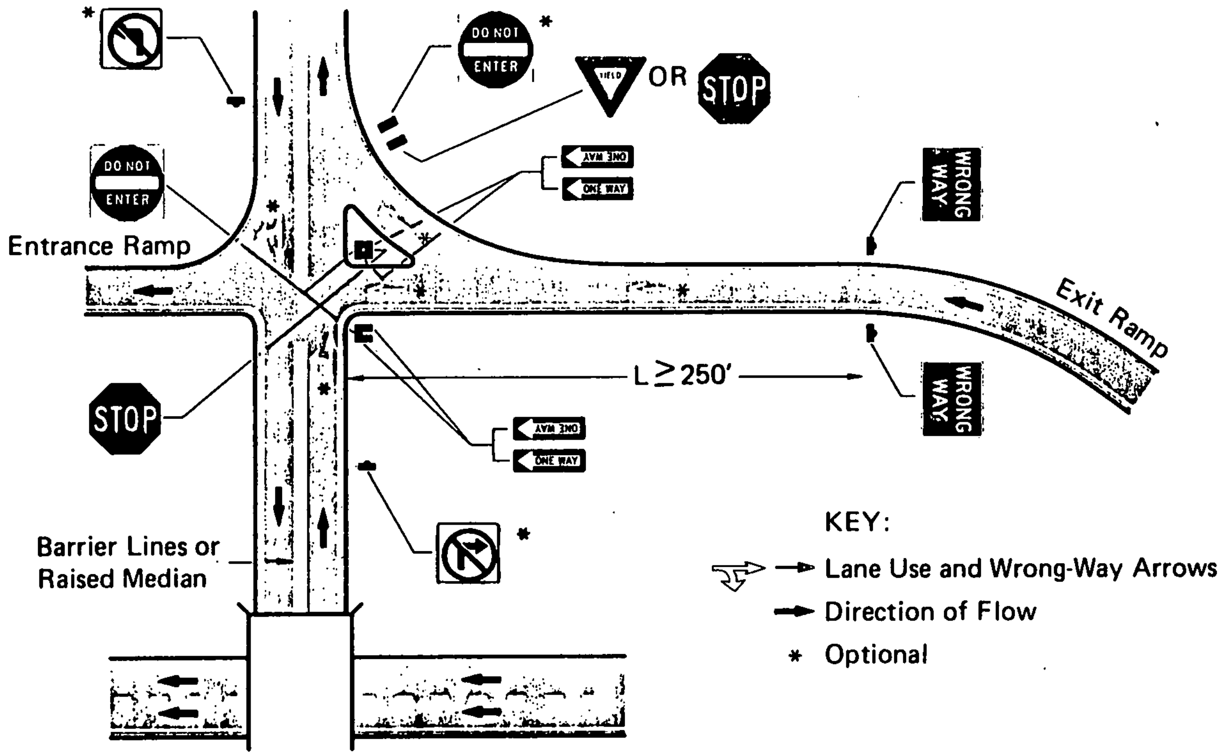


Figure 32. Application of Do Not Enter and Wrong Way signs on a freeway exit ramp.

have reached a divided highway with two separate roadways rather than an undivided roadway

The crossroad approaches are normally controlled with Stop signs, as a minor road entering a through highway or street is one of the warrants for a Stop sign in MUTCD Section 2B-5. The sight distance implications of these various choices of traffic control devices are examined in the subsequent section on ISD. The remainder of the signing is intended to help crossroad drivers to recognize the major road as a divided highway and to reduce the potential for wrong-way movements. The signs that help reduce wrong-way movements are the following:

- The One-Way sign (MUTCD sign R6-1 or R6-2)
- The Divided Highway Crossing sign (R6-3 or R6-3a)
- The No Right Turn and No Left Turn signs (R3-1 and R3-2)
- The Do Not Enter sign (R5-1)
- The Wrong Way sign (R5-9)

Typical applications of these signs (except for the Do Not Enter and Wrong Way signs) are illustrated in MUTCD Figures 2-3 and 2-3a.

MUTCD Figure 2-22a (presented here as Figure 32) illustrates the application of the Do Not Enter and Wrong Way signs. The Do Not Enter sign is used to tell drivers that entering the roadway where the sign is posted is prohibited. The sign is usually mounted on the right side of the roadway where it would face the traffic entering the wrong way. The MUTCD states that it may also be appropriate to mount a second sign on the left side of the roadway especially when the entering vehicle turns to enter the restricted road. The Wrong Way sign is often used to supplement the Do Not Enter sign on divided highways. The MUTCD states that the Wrong Way sign should be placed farther from the crossroad than the Do Not Enter sign. The issue of wrong-way movements at divided highway intersections is addressed further in a later section of this chapter.

MUTCD Figure 2-3 (presented here as Figure 30) shows the median roadway of a divided highway marked with stop bars and a double yellow centerline, much as a conventional roadway or street would be. This marking scheme appears to be quite effective in conveying the message to drivers that it is acceptable to cross the near roadway of the divided highway and then wait in the median before proceeding. There is very little guidance in the MUTCD or other sources on delineation requirements at divided highway intersections other than that shown in MUTCD Figures 2-3 and 2-3a.

Most unsignalized, divided highway intersections have two-way stop control; however, four-way stop control has been used at some divided highway intersections between major routes. There have been some studies on four-way stop control for higher-speed intersections. One study, by Briglia (*30*), found that accident rates declined by an average of 58 percent at 10 rural intersections in Michigan when two-way stop control was replaced by four-way stop control. The increased cost associated with the vehicle delays, however, would offset any savings from the reduced accident levels except at intersections with low or moderate mainline volumes.

Analysis of Field Observational Data

An analysis was conducted to examine driver compliance with traffic control devices on the median roadway and to ensure that a traffic control device effect was not mistaken for an effect of median width or median opening length. In particular, the analysis focused on the traffic control device used on the median roadway at its intersection with the far roadway of a divided highway.

Compliance with traffic control devices on the median roadway was evaluated in two ways. First, special substudies of Stop sign compliance were performed for four of the seven rural, unsignalized intersections at which Stop signs were used. These studies classified each vehicle passing through the median roadway as making a full stop or a rolling stop or running the Stop sign. Similar studies were not performed for intersections with yield control or no control on the median roadway because vehicles encountering such control are not required to stop but are required to yield the right of way to vehicles on the major road. The compliance or lack of compliance at intersections with yield control or no control can be judged only by determining whether vehicles departing from the median roadway created a traffic conflict by forcing a vehicle on the major road to brake or swerve. Therefore, the second analysis performed, which included rural, unsignalized intersections with all types of control on the median roadway, determined the number of conflicts observed between major-road vehicles and vehicles crossing or entering the major road *from the median roadway.* In other words, conflicts involving a crossroad vehicle entering or crossing the near roadway of the divided highway were not counted, but conflicts involving a crossroad vehicle entering or crossing the far roadway of the divided highway were counted. Such conflicts could involve four different types of vehicles using the median roadway: major-road vehicles making a left turn or a U-turn and crossroad vehicles making a through movement or a left turn.

The traffic control device compliance data are presented in Appendix B. For the intersections studied, driver noncompliance with Stop signs on the median roadway (failure to stop) ranged from 11.6 percent to 42.7 percent of vehicles using the median roadway. The percentage of drivers who made a rolling stop ranged from 30.8 to 39.0. A full stop was made by 22.9 percent to 50.0 percent of drivers on the median roadway. Although less than 50 percent of drivers generally comply fully with Stop signs on the median roadway, most of the drivers could have stopped if another vehicle were in the way. As shown in Table B-14 in Appendix B, no traffic conflicts resulted from these maneuvers. In fact, as shown in Table B-14, only four traffic conflicts between major-road vehicles and vehicles emerging from the median roadway were seen in the entire data set for rural, unsignalized intersections. These four conflicts all happened to occur at sites with yield control, but this sample size is too small to draw any conclusions about differences between the types of traffic control. It is apparent, however, that whatever type of traffic control is used on the median roadway, conflicts between major-road vehicles and vehicles emerging from the median roadway are rare.

There is no indication that the above findings concerning the effect of median width and median opening length on the rate of undesirable maneuvers in any way depend on the type of traffic control used on the median roadway.

As reported earlier in this chapter, it was observed that vehicles making opposing left turns tend to turn in front of each other at intersections with medians less than 15 m (50 ft) wide and to turn behind one another at intersections with medians more than 15 m (50 ft) wide. No indication was found that this turn-in-front/turn-behind behavior depended on the type of traffic control device used on the median roadway.

Signalized Intersections

Current Traffic Control Policies

There is little guidance in the literature or in traffic control device policies about the use and placement of traffic signals at intersections on divided highways. At some minimum median width, it becomes desirable to have separate signals on the minor road for each roadway of the divided highway; however, there are no formal policies on what this minimum median width should be. While little guidance is available on traffic signals that is specifically applicable to divided highway intersections, information is plentiful on the use of signals at intersections on higher-speed facilities. In an accident-based safety study of traffic controls at rural, high-speed intersections, Agent (*31*) observed that signalized intersections with high accident rates had problems with opposing left-turn (i.e., vehicles turning left from the major roadway) accidents. For these types of accidents, the most common anecdotal reasons for the accidents were that the left-turning drivers did not see the oncoming vehicles or that their vision was obscured. The sight distance requirements for this type of left-turn maneuver are addressed later in this chapter.

Numerous studies also exist on active warning devices at intersections (*32,33,34*). These devices include flashing Red Signal Ahead signs, flashing Prepare to Stop When Flashing signs, flashing beacons, and red signal lenses with flashing strobes. Each of these device types appears to improve the safety of signalized intersections on higher-speed roadways, and many of the locations where they have been applied are on divided highways in rural or suburban areas. Most of the evaluation studies, however, do not seem to account for novelty effects, which may last only until drivers become familiar with the device.

Simulation Analysis of Signalized Intersection Operations

A simulation analysis was conducted to determine the effect of median width and signal configuration on the efficiency of traffic operations at signalized intersections. The approach to this analysis is described earlier in this chapter and is presented in greater detail in Appendix E.

Figure 33 presents the effect of median width on total delay at signalized intersections for two sets of approach traffic volumes ("moderate" volumes corresponding to Level of Service B and "high" volumes corresponding to the boundary between Levels of Service C and D) and a set of typical turning movement patterns, presented in Appendix E, that has been termed the baseline scenario. Separate relationships to median width are shown in the figure for a single signal installation controlling both roadways of the divided highway and for separate signal

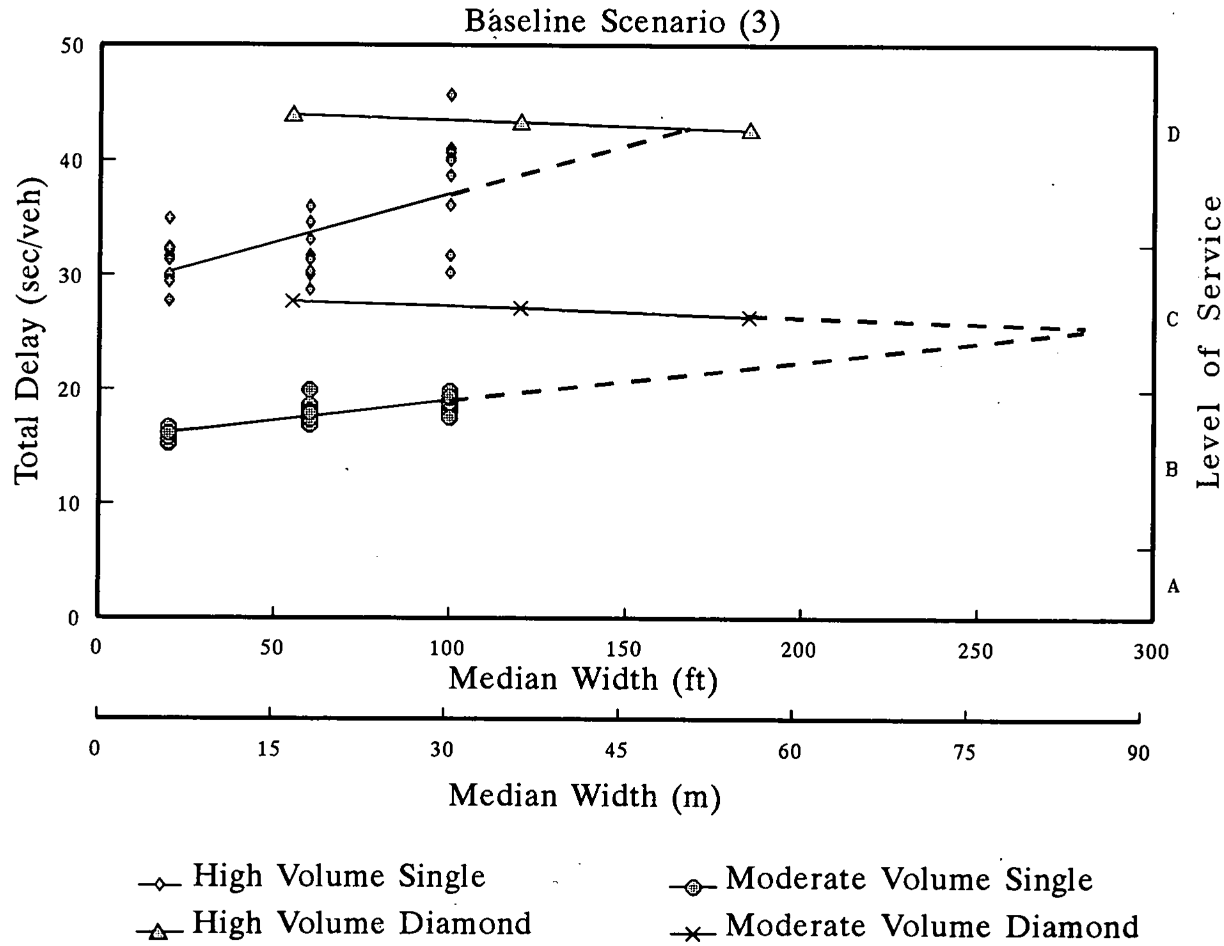


Figure 33. Illustration of the effect of increased median width on total delay at signalized intersections.

installations on the two roadways of the divided highway (equivalent to the type of signalization provided at a diamond interchange). Simulation models were used to obtain delay estimates for the single signal configuration for median widths of 6, 18, and 31 m (20, 60, and 100 ft) and for the diamond configuration for median widths of 17, 37, and 56 m (55, 120, and 185 ft); where the relationships in Figure 33 are extrapolated outside these ranges, they are shown as dashed, rather than solid, lines.

The figure shows that, within the range of median widths present at most divided highway intersections, the single signal installation operates with less total delay than the diamond configuration. For the single signal configuration, total delay increases as median width increases. For the moderate-volume level, as the median width increases from 6 to 31 m (20 to 100 ft), the total delay increases relatively little and remains within Level of Service B over this range; the slope of this relationship for the moderate-volume level is 0.12 sec/veh/m (0.036 sec/veh/ft). For the high-volume level, delay increases with median width at a steeper slope of 0.28 sec/veh/m (0.086 sec/veh/ft); over the range of median widths of 6 to 31 m (20 to 100 ft), the total delay increases from Level of Service C to Level of Service D.

For the diamond signal configuration, total delay decreases with increasing median width, but total delay is less sensitive to median width than for the single signal consideration. For both the moderate- and high-volume scenarios, the slope of the delay compared with median width relationship over the range of median widths of 17 to 56 m (55 to 185 ft) is -0.034 sec/veh/m (-0.010 sec/veh/ft).

Figure 33 shows that, for the moderate-volume level in the baseline scenario, the total delay for the single signal configuration remains less than for the diamond signal for median widths of up to approximately 85 m (280 ft). For the high-volume level in the baseline scenario, the point of equal delay for the single and diamond signal configurations occurs at a median width of approximately 49 m (160 ft). These points of equal delay were examined for each of the scenarios evaluated, as described in Appendix E. On the basis of these findings, a general recommendation is made that the single intersection configuration be used for median widths of less than 31 m (100 ft) and the diamond intersection configuration be used for median widths of more than 46 m (150 ft). For intersections with median widths between these values, an acceptable design can probably be accomplished using either strategy. Designers should be aware that for all single signal intersections with median widths of more than 18 m (60 ft), it is possible that vehicles may become trapped on

the median roadway at the end of the crossroad green phase, and the signal system should be designed to minimize this possibility (e.g., with vehicle detectors on the median roadway).

In summary, it appears that from a traffic operational point of view, the median width of a signalized intersection with a single signal should be kept as small as possible to minimize delay. Furthermore, to minimize delay, the diamond signal configuration should be avoided except at intersections where a wide median is needed for other reasons.

TRUCK CONSIDERATIONS

The field observational studies found no significant problems related to truck operations at the field study intersections. In general, truck drivers exercised good judgment about the length of their vehicles in relation to the median width. Furthermore, the accident evaluation of the field study intersections found that trucks were generally underrepresented in accidents at the study sites. Overall, trucks constituted 9.2 percent of the major-road traffic and 5.2 percent of the crossroad traffic at the study intersections, but trucks represented only 4.3 percent of the vehicles involved in accidents.

LEFT-TURN TREATMENTS

Current design practices for left-turn treatments at divided highway intersections have been discussed earlier in this chapter. Most of the field study sites had conventional left-turn lanes, and no particular traffic operational or safety problems related to these conventional left-turn lanes were found. Several intersections with innovative left-turn treatments, including tapered offset left-turn lanes, parallel offset left-turn lanes, and median acceleration lanes, were included in the field observational studies. The findings of these studies are summarized here and are presented in greater detail in Appendix D. These types of left-turn treatments are illustrated in Figures 8 and 9.

Tapered and Parallel Offset Left-Turn Lanes

The field observational studies included two signalized intersections with tapered offset left-turn lanes and one intersection with parallel offset left-turn lanes. Although the sample was very limited, no operational problems were observed related to median width or driver understanding of the offset left-turn lanes. In fact, during the daytime study periods, no undesirable driving behavior was observed at any of the three intersections. One undesirable driver action, involving a driver who missed the entrance to a tapered left-turn lane and then backed up in a through lane to return to it, was observed during a break in the field studies. Another undesirable maneuver was observed in a night study when a driver intending to turn left did not realize until the last moment the need to enter the tapered offset left-turn lane; the driver braked hard and swerved across the gore area from the left through lane into the tapered offset left-turn lane but did not run onto the curb in the gore area. In both of these maneuvers, no other traffic was present and, thus, no conflicts resulted.

These two undesirable maneuvers represent less than 0.1 percent of the traffic that used the offset left-turn lanes to make left turns during the study period. In fact, one of the maneuvers in question did not occur during the study period.

The accident history of the three field sites with offset left-turn lanes was reviewed. The two intersections with offset left-turn lanes experienced more left-turn accidents in 3 years on the crossroad approaches (which had conventional left-turn lanes) than on the major-road approaches (which had offset left-turn lanes). None of the intersections with tapered offset left-turn lanes experienced any problem with accidents related to wrong-way movements through the offset left-turn lanes. The intersection with parallel offset left-turn lanes experienced more left-turn accidents in 3 years on each of the three approaches with offset left-turn lanes than on the one approach with a conventional left-turn lane; however, the approach with the conventional left-turn lane also had the lowest left-turn volume of any of the four approaches to this intersection. In summary, the available data do not indicate any particular accident problems with tapered or parallel offset left-turn lanes. However, the available sample sizes of accidents and intersections are not sufficient to indicate that any particular left-turn lane design is superior.

All three study sites with offset left-turn lanes were located at signalized intersections. Offset left-turn lanes have also been used, on a more limited basis, at unsignalized intersections. However, in our search for field study sites, no unsignalized intersections were found with offset left-turn lanes and sufficient traffic volume to make a field study productive.

It should be noted that the field observational studies found that most undesirable driving behavior at unsignalized intersections involved competition for limited space between vehicles traveling in the same direction through the median roadway. Tapered offset left-turn lanes could potentially reduce such congestion by removing major-road left-turn vehicles from the median roadway. However, because tapered offset left-turn lanes have not been used extensively at unsignalized, four-leg intersections with higher traffic volumes, it is not known how effective they would be. An evaluation is needed to ensure that they are not confusing to drivers; furthermore, because major-road left-turn movements and traffic movements through the median roadway are not separated in time by signal phasing as they would be at a signalized intersection, it is important to establish that conflicts between these movements do not result in accidents. Because of these concerns, no recommendations have been made on the use of tapered offset left-turn lanes at unsignalized intersections.

Median Acceleration Lanes

Four intersections with one or more median acceleration lanes were included in the field studies. These intersections included three four-leg, unsignalized intersections with median widths of 16, 22, and 44 m (54, 72, and 144 ft) and a three-leg, unsignalized intersection with a median width of 11 m (36 ft). These studies found that median acceleration lanes 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; stopping in the median is not necessary to yield to through traffic on the divided highway but is necessary to yield to other traffic on the median roadway. Median accelera-

tion lanes work best when the acceleration lane is long enough to allow the accelerating vehicles to reach the speed of major-road traffic before merging into the through lanes.

Operational problems were observed at only one site where some left-turn drivers failed to use the median acceleration lane and several traffic conflicts with through vehicles resulted. However, it should be noted that the median acceleration lane did not cause these problems. The traffic conflicts created by the drivers who failed to use the median acceleration lane would have occurred in any case (perhaps in greater numbers) if the median acceleration lane were not present.

INTERSECTION SIGHT DISTANCE

ISD is an important design and operational consideration at all intersections. 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 AASHTO policy on ISD design is presented on pages 696 through 721 of the AASHTO Green Book (*1*). The Green Book 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 their included corners (the so-called "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 intersection with the two roadways of the divided highway can be determined separately.

The minimum median width that would generally be considered adequate to store a passenger car is 7.6 m (25 ft), on the basis of the 5.8-m (19-ft) length of the AASHTO passenger car design vehicle. Wider medians would be required to safely store a 12.1-m (40-ft) bus or a tractor-semitrailer truck (currently up to 22.5 m [75 ft] long). The choice of the design vehicle is important for ISD on divided highways because there obviously is a range of median widths wide enough to store a passenger car but not wide enough to store a longer vehicle.

An extensive reexamination of existing ISD design policies and practices was done in NCHRP Project 15-14(*1*). That research is expected to recommend revisions to current ISD design policies, including policies applicable to divided highway intersections. Because this related work is not yet complete, the following discussion identifies the situations where ISD requirements for divided highway intersections may differ from undivided highway intersections but does not recommend specific changes in ISD criteria.

The AASHTO policy provides geometric design criteria for five ISD cases, which are defined briefly in this section. One of the five cases has three subcases so there are, in effect, seven ISD cases. These seven cases are defined by the type of traffic control present at the intersection and the types of maneuvers that the drivers intend to make. The seven cases are the following:

- Case I—ISD for vehicles approaching intersections with no control, at which vehicles are not required to stop but may be required to adjust speed
- Case II—ISD for vehicles on a minor-road approach controlled by a Yield sign
- Case IIIA—ISD for a vehicle on a Stop-controlled approach on the minor road to accelerate from a stopped position and cross the major road
- Case IIIB—ISD for a vehicle on a Stop-controlled approach on the minor road to accelerate from a stopped position and turn left into the major road
- Case IIIC—ISD for a vehicle on a Stop-controlled approach on the minor road to accelerate from a stopped position and turn right into the major road
- Case IV—ISD for a vehicle on a signal-controlled approach
- Case V—ISD for a stopped vehicle turning left from a major road

Each ISD case and its applicability to divided highway intersections is summarized briefly below.

ISD Case I—Intersections with No Control

ISD Case I is not generally applicable to divided highway intersections because such intersections are seldom operated with no control on any of the approaches.

ISD Case II—Yield Control on Minor Road

The use of yield control on the crossroad approaches to a divided highway intersection is unusual because an intersection of a less important road with a main road is one of the MUTCD warrants for use of a Stop sign. Thus, ISD Case II is not generally applicable to the crossroad approaches to divided highway intersections. Furthermore, because the current AASHTO model for ISD Case II is based on a stopping maneuver, rather than a crossing maneuver, the ISD requirements for Case II do not vary as a function of median width; however, if it is necessary for a driver of a vehicle on a yield-controlled approach to stop because of traffic on the major road, wider medians may require more ISD for crossing and turning maneuvers as the vehicle accelerates from a stop. This is discussed further in ISD Cases IIIA, IIIB, and IIIC below.

Although yield control is not often used on the minor-road approaches to divided highway intersections, yield control is frequently used at the intersections of the median roadway with the divided highway. Thus, there is a need to consider ISD Case II for vehicles on the median roadway; however, the sight distance needs for vehicles facing a Yield sign on the median roadway do not depend on the median width, because the presence of a Yield sign in the median presupposes that enough

space is in the median for a vehicle to stop safely and wait for a suitable gap in the major-road traffic.

ISD Case IIIA—Stop Control on Minor Road: Crossing Maneuver

ISD Case IIIA applies to the sight distance requirements for a minor-road vehicle to cross a major roadway. On divided highways with medians wide enough to store a vehicle, the sight distance requirements for crossing each roadway are determined separately. Thus, for this situation, ISD requirements would not be a function of median width. If the median is not wide enough to store a vehicle, however, then the crossing of both roadways and the median must be performed in a single maneuver—thus, for narrower medians, the ISD that should be required for Case IIIA increases as the median width increases. In this case, the path length used to determine ISD should include the width of both roadways of the divided highway and the median width.

ISD Case IIIB—Stop Control on Minor Road: Left-Turn Maneuver

ISD Case IIIB applies to the sight distance requirements to turn left from a stop-controlled approach onto a major road. Where the median is wide enough to store a vehicle, provision of the required sight distance for Case IIIC will also provide enough sight distance for vehicles to cross the near roadway of the divided highway. Sight distance for Case IIIB should be provided for vehicles to turn left from the median roadway onto the far roadway of the divided highway; however, the sight distance requirements for this maneuver are no different from those for a left turn onto an undivided highway and are not influenced by the median width.

Where the median is not wide enough to store a vehicle, Case IIIB sight distance should be provided on the crossroad approach. In this situation, the Case IIIB sight distance must allow for the time to cross the near lanes and for the time to cross through the median. Thus, in this situation, the sight distance requirement for Case IIIB is a function of the median width. In the current AASHTO model for ISD Case IIIB, that can be accomplished by including the width of the near lanes of the divided highway plus the median width to the distance to be traveled by the turning vehicle.

ISD Case IIIC—Stop Control on Minor Road: Right-Turn Maneuver

ISD Case IIIC deals with the sight distance required to turn right from a minor-road stop-controlled approach onto a major road. The sight distance requirements for right turns are independent of median width and are unaffected by whether the highway onto which the crossroad vehicle is turning is divided or undivided.

ISD Case IV—Signal Control

ISD Case IV addresses the sight distance requirements for vehicles on signalized intersection approaches. The AASHTO policy for Case IV notes that the required sight distance for Case III should be provided at signalized intersections. This policy applies to signalized intersections on both divided and undivided highways. The differences in the underlying criteria for ISD Cases IIIB and IIIC between divided and undivided highways were discussed above.

ISD Case V—Left Turns from the Major Road

The 1994 AASHTO Green Book introduced a new ISD case on the basis of the policy on sight distance requirements for left turns from the major road that first appeared in the 1990 Green Book (*1,2*). The required left-turn sight distance is defined by the equation:

$$SD_{req} = 0.28\ V\ (J + t_a) \tag{2}$$

where

SD_{req} = sight distance required to safely complete a left turn off a major road (m)
V = speed of vehicle on a major road (km/h)
J = perception-reaction (PR) time (sec) (assumed: J = 2.0 sec)
t_a = time required for a turning vehicle to accelerate and travel a length equal to d_a (sec)
d_a = length of vehicle's turning path to clear opposing lanes (i.e., path length to curb line plus vehicle length) (m)

The time required to traverse the distance d_a can be determined from Green Book Table IX-8. At a divided highway intersection with a median that is not wide enough to store a turning vehicle, the path length used to determine d_a should include the vehicle's turning path across both the median and the opposing lanes of the divided highway. Where the median is wide enough to store a turning vehicle, the path length needs to include only crossing of the opposing lanes, and the ISD criteria for left turns off the major road become equivalent to the ISD criteria for the crossing maneuver in Case IIIA.

The sight distance for left-turning vehicles at divided highway intersections may be limited by fixed sight obstructions on the roadside and by opposing left-turn vehicles. Appendix F presents equations based on the work of McCoy et al. (*35*) that can be used to determine the offsets between opposing left-turn lanes that will eliminate or minimize sight obstructions caused by opposing left-turn vehicles.

HUMAN FACTORS/DRIVER PERCEPTION CONSIDERATIONS

The review of the literature in this area focused on driver performance characteristics that affect the design of intersections. None of the available information is specifically applicable to divided highway intersections.

Perception-Reaction Time

Generally, perception-reaction time has been thought to be the time needed to perceive some stimulus, and, if necessary, the time needed to take some type of action in response. Numer-

ous studies have attempted to analyze the component parts of what has simply been called perception and reaction. The general concept of perception has been described as being made up of sensation, detection, eye movement latency, eye movement, fixation, accommodation, perception, cognition, recognition, intellection, comprehension, decision, and emotion. Some of these terms describe the same element or parts of the same element. The reaction component is thought to be made up of just a simple reaction (or volition or action response) element. The reaction can be a movement response of almost any type (e.g., for driving applications, foot from accelerator pedal to brake pedal or foot off accelerator pedal).

One approach for calculating the time element related to human operators of different systems has been to measure values for several of the constituent elements and add up these time segments to determine an appropriate perception-reaction time. Another approach has been to calculate percentile values for the measurable elements and assemble these percentile values into some single value or range of values for perception-reaction time. These approaches have several potential disadvantages. One disadvantage is the implicit assumption that the elements of the perception-reaction process act in series without any time overlap or parallel functioning. Another disadvantage is that it is highly unlikely that an individual will consistently perform at or near specified percentile values for all the individual elements of the perception-reaction process (*36*). Other researchers have proposed perception-reaction models that are probabilistic. Such models have similarities with signal detection theory and Bayesian decision theory; however, there is no one analytical approach (including the additive factors approach described above) on which researchers generally agree (*36*).

Additional attempts to determine perception-reaction times have taken the form of empirical studies of the entire perception-reaction process. Given our analytical models of perception-reaction time, studies that measure the entire perception-brake-reaction time are usually preferred over those studies that attempt to measure the individual components and then add them together. In these studies, measurements are made from the onset of the perception process through the completion of the reaction component and the onset of mechanical acceleration or braking; however, many of these studies tend to be deficient in that the subjects are already alerted that their reactions will be tested.

Detection and Recognition of Objects and Vehicles

The principal problem for the driver in all sight distance situations is detecting and identifying other vehicles. Detection and recognition is primarily a matter of visual search and target acquisition. Research on visual search has generally focused on models of search time and the identification of factors that influence the speed of the search (*36*). Much of this research is based, however, on subjects' abilities to search for and identify letters or numbers from an array. Boff and Lincoln (*37*) (in Fambro et al. [*38*]) maintain that target acquisition is affected by brightness (luminance), texture contrast (including color), texture gradients (boundaries), dimensions of the target, dynamics, and environmental factors.

From an applied standpoint, most (if not all) of the research related to visual search and object recognition related to highway design has concentrated on the 102- and 153-mm (4- and 6-in) objects that have been used for SSD considerations (*38,39,40*). Although many of these studies provide useful information regarding the stopping sight distance (SSD) problem, none of these studies addresses the basic issues related to ISD requirements.

Besides identifying other vehicles, drivers on the minor road at intersections on divided highways must also detect and recognize that there are two one-way roadways separated by a median. Recognizing this situation is one of the cues that prevents wrong-way driving. Principally, the driver depends on a clear line of sight to the far roadway of the divided highway so that he or she can identify that roadway and recognize it as the remaining half of a divided highway. Problems occur when the design of the highway cross section makes it difficult for the motorist to see the other roadway or intersection (*41*).

Older Drivers

In recent years, there have been several excellent studies of older drivers that address their declining functional capacities particularly, visual, cognitive, and psychomotor performance. Reports by Staplin (*42*); Dewar, Templar, and Knoblauch (*43*); and Shinar and Scheiber (*44*) summarize most of the important research findings related to older driver and pedestrian performance.

The performance of several different visual functions deteriorate with age. Older drivers have reduced contrast sensitivity. Visual acuity changes begin at age 40. The decline is slow at first but accelerates after 60 or 70. Other visual problems include a loss in the size of the visual field area (the field of view). Changes in the visual field can be measured as a reduction in field area or as an elevation in detection thresholds at locations within the field.

Although it is important to note these various changes in visual performance of the elderly, it is equally important to recognize that many studies have shown driving performance is not inextricably linked to visual performance. Many accidents in which human error is cited also seem to have some cognitive performance problem as a contributing factor.

Changes in cognitive capabilities occur with aging. These changes are associated with behaviors such as attention span, visual search behavior, memory functions, and complex problem solving. Older drivers are known to have problems with visual search capabilities. For example, when asked to search for target stimuli, older drivers decide more slowly and generally make more mistakes in identification. Older people have difficulty refocusing on a specific task when asked to perform other tasks — this can cause problems when older drivers are performing tasks such as locating destinations or looking for places to make turns. Memory is very important in the synthesis and management of sensory information to solve problems. Memory interacts with decision and response functions. These functions are critical for driving, because control, traffic, and alignment information must be attended to and stored temporarily to give the driver information to control the vehicle and plan the next maneuver.

Reaction time slows with age; however, brake reaction time is slowed by only 0.1 sec for a 75-year-old as compared with a 25-year-old test subject (*45*). Researchers examining actual on-road behavior have not found any significant age effects related

to brake reaction time (*46,47*). Reactions to simple, well-defined stimuli (i.e., a situation corresponding to an SSD case) have been found to be very similar for older and younger subjects; problems, however, have been observed in situations with hazards that have a high cognitive element. If a hazard is not easily recognized as such or the choice of an appropriate maneuver is difficult, the older driver may take 2 or more seconds longer to react.

There are several things to consider when interpreting data concerning the performance of older drivers. One consideration is older drivers' self-imposed limitations on their driving behavior. Older drivers will avoid many conditions that they consider hazardous or situations in which they feel uncomfortable or confused when driving. For example, many older drivers avoid peak-hour conditions. Some will not drive at night. Others will not drive on higher-speed, limited-access facilities. These behavior patterns should be considered by researchers in drawing conclusions on the basis of raw accident frequencies or other measures.

Intersection Design Issues

TRB Special Report 218, Transportation in an Aging Society (*48*), submits that one of the more pressing roadway design issues related to older drivers is the left turn off the mainline. It is acknowledged that older drivers generally have problems selecting gaps in oncoming traffic and estimating the speeds of approaching opposing vehicles. The report proposes the development of formal warrants and greater use of dedicated left-turn lanes and protected left-turn signal phasing.

Although there is little evidence that older drivers react more slowly than other motorists, they do take more time to make decisions. This decision-making time can be even longer if the older driver is confronted with a particularly complicated geometric or traffic control situation.

There is also some concern that older drivers may have a reduced range of head and neck movements. A simulator study of decision times of old and young drivers with restricted neck movement by Hunter-Zaworski has confirmed this concern (*49*). Although the younger subjects with restricted movement could compensate for their impairment, all older drivers, with and without movement problems, had longer decision times. One finding of this study was that skewed intersections are particularly troublesome for all drivers with restricted movement.

In a recent project related to older driver perception-reaction time for ISD and object detection, experimental results by Lerner et al. have shown no difference in the performance of older and younger drivers in perception-reaction time measures related to several aspects of highway geometric design (*46*). In fact, this series of experiments confirms that the 2-sec perception-reaction time used for ISD Case III in the AASHTO Green Book is appropriate for older and younger driving populations. This finding adds weight to the idea that most intersection accidents are related to higher cognitive functions such as attention or multitask processing lapses.

DRIVER EXPECTANCY ISSUES

Two primary issues related to driver expectancy should be noted in designing divided highway intersections: driver expectations concerning the turning paths of potentially conflicting vehicles and the potential for wrong-way movements.

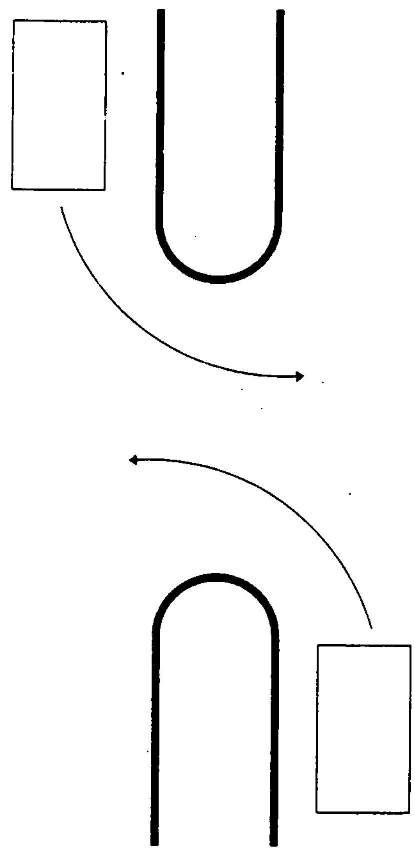


Figure 34. Paths of left-turning vehicles turning in front of one another.

Driver Expectations Concerning Turning Paths

A key issue in selecting median widths and designing intersections on divided highways is whether the design of the intersection leads drivers to believe that left turns in the median area should be made in front of or behind an opposing left-turning vehicle (see alternative turning paths in Figures 34 and 35).

Little information is in the literature on driver choices between "turn-in-front" and "turn-behind" maneuvers. Therefore, much of the information reported here is based on anecdotal information heard during visits to the various state highway agencies and field observations made during the research.

The "turn-in-front/turn-behind" issue is driven by several geometric and operational factors. In relatively narrow medians with left-turn lanes or narrow median openings, there is seldom any confusion regarding this matter, and, except for rare instances, the left-turning vehicles turn in front of each other (see Figure 34). When medians are very wide, to the point where the median area roadway functions like a small street between the intersections, there is usually little confusion about which turning path is used, so the left-turning vehicles turn behind each other (see Figure 35). Driver decision making at wide-median intersections

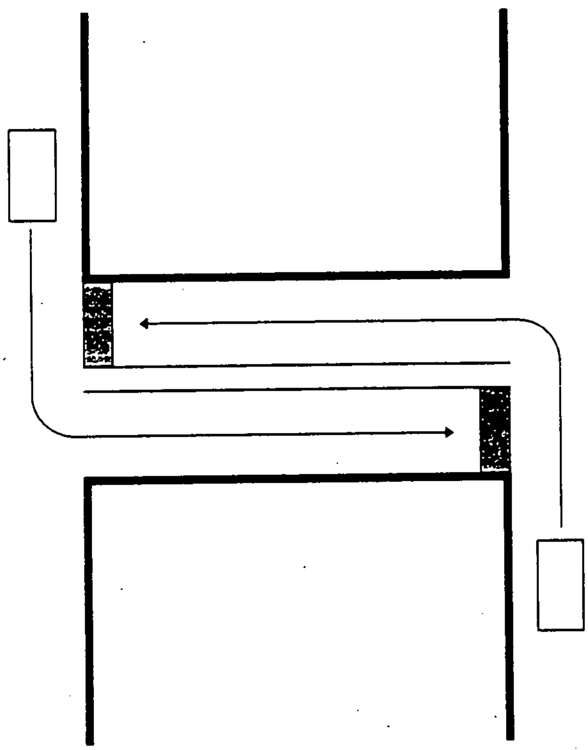


Figure 35. Paths of left-turning vehicles turning behind one another at a wide-median intersection.

can be aided by adding pavement markings in the median area (e.g., center lines and stop bars).

Because substantial uncertainties existed about the ranges of median width at which turn-in-front and turn-behind behavior would be observed, the field observational studies addressed this issue. As described earlier in this chapter, it was found that turn-in-front behavior predominates for intersections with medians less than 15 m (50 ft) wide, and turn-behind behavior predominates for intersections with medians more than 15 m (50 ft) wide.

Wrong-Way Movements on Divided Highways

Wrong-way movements are a definite cause of accidents on divided highways, including freeways and divided highways without full access control (expressways and arterials). Six types of wrong-way movements can lead to accidents on divided highways without full access control (*50*):

1. Left turn into the near lanes at an intersection — Drivers arriving at a divided highway on a minor-road approach may turn left by mistake into the near roadway of the divided highway.
2. Right turn into the far lanes at an intersection — Drivers arriving at a divided highway on a minor-road approach may turn right by mistake into the far roadway of the divided highway.
3. Left turn at an access point with no median opening—Many minor access points on divided highways do not have median openings — this forces drivers who want to turn left to turn right instead, travel until they reach a median opening, and then make a U-turn to proceed in the desired direction. Either by intent or by mistake, drivers occasionally make a left turn at the minor access point and travel the wrong way on the near roadway of the divided highway.
4. Crossing the median — Occasionally drivers are inattentive or fall asleep and drive across the median without realizing it. They sometimes drive for some distance unaware of what has happened.
5. Transitions — Drivers entering a transition from an undivided highway to a divided highway sometimes drive down the lanes on the wrong side of the divided highway.
6. U-turns — Drivers may make a U-turn on one roadway of a divided highway and return in the direction from which they came; however, this is less common on divided highways without access control than on freeways (where drivers may be tempted to turn around if they miss an exit ramp).

The first two types of wrong-way movements occur at divided highway intersections and bear a direct relationship to the geometric design and the traffic control devices at the intersection.

A 1969 California study (*51*) quantified the relative frequency of these types of maneuvers (see Table 18) on divided highways without full access control. The table shows that 47 percent of wrong-way movements on divided highways originated at access points with median openings (primarily intersections). Similar results from a 1972 Virginia study (*52*) (shown in Table 19) found that 45 percent of wrong-way movements on divided highways originated at intersections. Thus, intersection design and traffic control may play an important part in minimizing wrong-way movements on divided highways.

The literature concerning wrong-way movements on divided highways (including studies in California, Indiana, Texas, and Virginia) documents the following findings:

1. Wrong-way accidents generally account for less than 1.5 percent (and often less than 1 percent) of a state's total accidents (*51,52,53*).
2. Wrong-way accidents generally account for between 1 and 2 percent of a state's fatal accidents. The data show that accidents involving wrong-way movements are generally more severe than other accidents (*50,51,52,53*).
3. Wrong-way movements are far more numerous than wrong-way accidents (*51,52,53*).
4. A disproportionate percentage of wrong-way movements occur on Friday, Saturday, and Sunday (*51,52,53*). This may be attributable to the greater number of intoxicated drivers on the road on weekends (*48*). Several studies have shown that more than half of all wrong-way drivers have been drinking (*50,52,54*). It should be noted, however, that drivers are also more likely to be traveling on roads with which they are not familiar on weekends than on weekdays.
5. More than half of all wrong-way movements occur under restricted visibility conditions, especially at night (*50,51*). Artificial lighting would probably reduce the likelihood of wrong-way movements at most divided highway intersections (*50*).
6. The peak hour for accidents involving wrong-way movements is between 2 and 3 a.m. (*51*). This is consistent with the hypothesis that drunk driving plays an important role in wrong-way movements.

TABLE 18. Origins of wrong-way movements that resulted in accidents on divided highways without full access control in California *(51)*

Point of origin	No. of wrong-way movements	Percentage of wrong-way movements
Intersection with median opening	67	47.2
Transition to divided highway	7	4.9
Drove through median opening (no intersection)	35	24.7
Drove across median	4	2.8
Made U-turn	26	18.3
Other (driveways)	3	2.1
	142	100.0
Origin unknown	25	
	167	

TABLE 19. Origins of wrong-way movements that resulted in accidents on divided highways without full access control in Virginia *(51)*

Point of origin	No. of wrong-way movements	Percentage of wrong-way movements
Intersections	70	45.2
Interchanges	10	6.5
Commercial driveways	38	24.5
Private driveways	14	9.0
Crossovers	16	10.3
U-turns	7	4.5
	155	100.0
Origin unknown	19	
	174	

7. Accident-involved wrong-way drivers have previous accident rates and traffic violation rates that are more than twice the average *(51)*.
8. Accident-involved wrong-way drivers have slightly less driving experience than the average driver *(51)*.
9. Most wrong-way movements tend to originate from areas of less-developed land use *(50)*.
10. Wrong-way movements take place when traffic volumes are low; i,e., when very little traffic is present to make the proper travel directions clear *(50)*.
11. Signing at most intersections where wrong-way movements take place is adequate. Thus, wrong-way movements seem to occur despite signing that meets the MUTCD requirements *(50)*.
12. Geometrics that are complex and hard to understand are a factor in wrong-way movements *(50)*.

The following geometric design guidelines for reducing the likelihood of wrong-way movements on divided highways were developed in an Indiana study *(50)*:

1. At the intersection of a divided highway with an undivided highway, the elevation of the undivided highway should be equal to or greater than that of the divided highway. This gives the approaching motorist on the undivided highway a clearer view of both directions of travel.
2. Whenever possible, angles of intersection other than 90 degrees, as well as unusual intersection layouts, should be avoided. Such layouts are frequently confusing and may encourage wrong-way movements.
3. At intersections where median storage is not required, medians should be narrow but distinct. Narrowing the median makes the far lanes of travel more visible, improving the driver's visibility of the overall intersection. Narrowing the median also reduces the amount of unchannelized space that the driver must negotiate. The median should be distinct to

aid the driver in understanding the intersection layout and function. Distinctiveness can be achieved by raising and coloring the median.

This Indiana study suggests that wider medians are more likely than narrow medians to be confusing to motorists, thus increasing the likelihood of wrong-way movements (*50*). The study did not, however, present any quantitative guidelines on median width to assist designers.

One of the issues that prompted this research was a concern that divided highways with wider medians, particularly in rural areas, could lead to driver confusion that could, in turn, result in wrong-way movements and accidents. Very little evidence of this problem was found in the data collected during the research and, in fact, intersections with wider medians were found to be the safest divided highway intersections in rural areas. Only one wrong-way movement was seen in the field observational studies and only one accident involving a wrong-way movement occurred during the study period at the field study sites. Nevertheless, because of the historical experience reported in the literature, the concern about wrong-way movements persists. It is appropriate for design guidelines to stress the need to ensure, through geometric design and traffic control, that the nature of divided highway intersections with wider medians is apparent to drivers.

CHAPTER 3

INTERPRETATION, APPRAISAL, APPLICATION

The findings presented in Chapter 2 illustrate the traffic operational and safety effects of median width and related geometric features at divided highway intersections. These findings provide a basis for selecting appropriate median widths and other design features for rural and suburban intersections on divided highways. This chapter summarizes the key factors in selecting the median width at divided highway intersections, the advantages and disadvantages of various median widths, and the feasible left-turn treatments for various median widths. The chapter then presents recommended guidelines for selecting the median width at divided highway intersections and guidelines for other design features at such intersections. The chapter also discusses potential revisions to the AASHTO Green Book to implement the recommendations in this chapter.

KEY FACTORS IN SELECTING THE MEDIAN WIDTH AT A DIVIDED HIGHWAY INTERSECTION

Table 20 summarizes these key factors. The research findings have shown that the area type (rural versus urban/suburban) is a key factor in selecting the median width. The traffic volumes and vehicle mix at the intersection—most particularly the crossroad traffic volumes and the volume of turns from the divided highway—are controlling factors in all aspects of the design. The turning volumes and vehicle mix are critical elements in determining the appropriate design vehicle to be considered, the type of traffic control to be employed, the left-turn treatments to be used, and the crossroad width and cross section. In turn, the selected design vehicle, traffic control type, left-turn treatment, and crossroad cross section define the other required intersection geometrics.

Sight distance is another factor that may enter into the selection of an appropriate median width. Chapter 2 of this report has explained the influence of median width on sight distance requirements at divided highway intersections. Sight distance may also influence the choice of left-turn treatments because of the potential need to offset left-turn lanes to minimize or eliminate sight obstructions caused by opposing left-turn vehicles.

ADVANTAGES AND DISADVANTAGES OF VARIOUS MEDIAN WIDTHS

Current design policies and the literature review have shown some clear advantages and disadvantages of various median widths; however, the median width ranges to which these advantages and disadvantages apply have not been quantified well enough to provide much specific guidance for designers. The following discussion addresses roadways with raised or depressed medians but does not address roadways with flush medians.

Table 21 summarizes the advantages of increasing the median width on divided highways. The AASHTO Green Book states clearly that some of the advantages of using medians can be obtained from medians of any width, even medians as narrow as 1.2 m (4 ft). In most cases, however, these advantages increase as the median width increases. The desirability of providing wider medians at intersections is highlighted by the list of disadvantages of narrow medians presented in Table 22. These disadvantages generally apply to raised medians that are less than 4 m (14 ft) wide (and are thus too narrow to include a left-turn lane) and raised medians between 4 and 7 m (14 and 24 ft) wide (which may include a left-turn lane but may not be wide enough to store a passenger car with adequate clearances to through traffic). A minimum median width of 7.6 m (25 ft) is generally considered adequate to store the 5.8 m (19-ft) AASHTO passenger car design vehicle with adequate clearances to through traffic. Passenger car lengths have been decreasing—For the 1990 model year, the maximum length of passenger cars (including minivans) produced in the United States was 5.6 m (18.4 ft), which is approximately 0.3 m (1 ft) less than the comparable maximum length of passenger cars in the 1978 model year. Many passenger cars now have lengths of only 4.6 to 4.9 m (15 to 16 ft) (*56*). It is recommended, however, that median width continue to be based on a design vehicle 5.8 m (19 ft) long unless AASHTO decides to reduce the length of the passenger car design vehicle.

The minimum median width required to store a crossing or left-turning vehicle safely in the median is a key factor in selecting the median width at an intersection. Of course, this minimum median width varies with the design vehicle selected. Thus, medians widths from 8 to 24 m (26 to 80 ft) are in an intermediate range that may allow storage of some design vehicles with adequate clearance to the through traffic lanes but not others.

As raised or depressed medians become wider, the disadvantages in Table 22 can be reduced or eliminated, but other disadvantages may develop. Table 23 summarizes the disadvantages of wide medians. One common cause of problems is driver confusion about the intended operation and turning paths at wide-median intersections. In addition, intersections with wide medians do not lend themselves to signalization where the median width exceeds 18 m (60 ft). Separate signalization on the two roadways of the divided highway may be considered, but this approach (which is equivalent to the signalization used at a diamond interchange) typically involves more delay than a single signal installation; this approach also requires careful at-

TABLE 20. Key factors to consider in selecting the median width at a divided highway intersection

Area type:
-- rural.
-- urban/suburban.
Crossroad through and turning volumes and vehicle mix.
Volume and vehicle mix for turns from the divided highway.
Appropriate design vehicle for crossing and turning movements.
Type of traffic control to be employed:
-- signalized intersection.
-- unsignalized intersection that may be signalized in the future.
-- unsignalized intersection that is unlikely to be signalized in the foreseeable future.
Crossroad width and cross-section (including travel lanes, shoulder, and median [if any]).
Left-turn treatment to be utilized.
Needs for U-turns on the divided highway.

TABLE 21. Advantages of increasing the median width on divided highways

Interference from opposing traffic is minimized.
A feeling of greater freedom is provided.
An increased recovery area is provided for out-of-control vehicles.
More open green space is provided and a parklike setting can be created.
Headlight glare from opposing vehicles is reduced.
Flatter slopes can be used in the median.
The need for a median barrier may be avoided.
Additional width is available for future construction of additional lanes.
Additional width is available for median left-turn and U-turn storage lanes.
Offset left-turn lanes can be constructed to minimize sight restrictions caused by opposing left-turn vehicles.
Additional width is available for median acceleration lanes where needed.
U-turns are feasible for larger vehicles.

tention to the storage requirements on the median roadway to avoid overflowing of vehicles from the median roadway onto the through lanes of the divided highway.

At divided highway intersections with very wide medians, where crossroad drivers approaching one roadway of the divided highway cannot see the other roadway, drivers may not realize that the roadway is divided and may turn in the wrong direction. Even if the other roadway is in view across a wide median, crossroad drivers may not see it, particularly at night or where the far roadway is at a lower elevation than the near roadway (*50*). Although no major problems of this type were found in the field and accident studies conducted as part of this research, care should be taken in both intersection design and signing to minimize such problems.

The following ranges of median width for raised or depressed medians are appropriate for particular vehicle types:

- 1.2 to 4 m (4 to 12 ft); not wide enough to provide a left-turn lane
- 5 to 7 m (14 to 24 ft); wide enough to provide a left-turn lane but not wide enough to store a crossing or turning passenger car with adequate clearance to through traffic
- 8 to 13 m (26 to 44 ft); wide enough to store a crossing or turning passenger car but not wide enough to store a school bus with adequate clearance to through traffic
- 14 to 24 m (46 to 80 ft); wide enough to store a school bus or several passenger cars but not wide enough to store a large tractor-semitrailer truck with adequate clearance to through traffic
- More than 24 m (more than 80 ft); wide enough to store all current AASHTO design vehicles other than longer combination vehicles (LCVs) but potentially confusing to some motorists.

Thus, the design vehicle selected is a key factor in determining median width requirements at divided highway intersections. The ranges of median width identified above are based on all current AASHTO design vehicles except LCVs (e.g., turnpike doubles and triple-trailer trucks), which do not frequently use nonfreeway divided highways and even less frequently make turning or crossing maneuvers on such highways.

TABLE 22. Disadvantages of narrow medians at divided highway intersections

Crossing and turning maneuvers may require simultaneous gaps in traffic in both direction of travel if the median is not wide enough to store a vehicle.
Vehicles may encroach on the through lanes while waiting in the median if drivers stop and wait in a median that is not wide enough to store their vehicles.
If the median is just wide enough to store one vehicle, more than one driver at a time may be tempted to use it. The second vehicle may encroach upon the through lanes or the two vehicles may wait side by side in the median, creating confusion about which vehicle has the right of way and potential conflicts.
Narrow medians make it difficult for trucks to make U-turns.
Vehicles turning left from the divided highway are required to wait in the inside (higher-speed) lane for a gap in opposing traffic when the median is too narrow for a left-turn lane to be provided.
Provision of single or double left-turn lanes may not be feasible if the median is too narrow.
Increased costs for widening the median will be incurred to provide left-turn lanes when they prove necessary.
Narrow medians may require installation of a median barrier which is difficult to terminate properly at intersections.
Narrow medians may not provide an adequate pedestrian refuge area [generally a 1.2- to 1.8-m (4- to 6-ft) median is required as a safe refuge for pedestrians].
Narrow medians may not provide a safe refuge area for bicyclists.

TABLE 23. Disadvantages of wide medians at divided highway intersections

Drivers may become confused abut the appropriate path through large paved area typically present on the median roadway of a wide median intersection.
Drivers may ignore or fail to see traffic control devices in the median intended to control movements onto or across the far roadway of the divided highway. Drivers may fail to stop before entering the far roadway when they are required to do so.
Drivers approaching from the crossroad who fail to see the far roadway may turn in the wrong direction because they do not realize that they are entering a divided highway.
Crossing or turning vehicles may overflow the available storage area.
Sight distance for vehicles turning left from the divided highway may be restricted by opposing left-turn vehicles.
If the crossroad also has a wide median, a very large and confusing intersection may result.
Wider medians require longer clearance times and, thus, longer and less efficient signal cycles if the intersection is signalized.
Wide medians make it difficult to place left-turn signal heads so that they are still visible if left-turning vehicles move forward toward the center of the intersection.
Long clearance times at intersections with wide medians make it possible for crossroad vehicles to be trapped in the median when the major-road green phase begins.
If the median is wide enough, the intersection may have to be signalized as two closely spaced intersections; closely spaced intersections are less efficient than a single intersection and are difficult to signalize properly.
Signal phasing and clearance times at intersections with wide medians can be inappropriate for bicyclists who attempt to use the vehicle timing.

FEASIBLE LEFT-TURN TREATMENTS FOR VARIOUS MEDIAN WIDTHS

The left-turn treatment selected for a divided highway intersection may be a key factor in selecting the median width. Tables 24 and 25 present the feasible left-turn treatments for specific median widths for intersections on divided highways with raised or depressed medians. Table 24 shows the feasible allocations of median width for single left-turn lanes; double left-turn lanes;

TABLE 24. Feasible allocations of available width for various median widths and left-turn treatments

	No LTL	Single Left-Turn Lane			Double Left-Turn Lanes			Parallel Offset Left-Turn Lane					Tapered Offset Left-Turn Lane				
Median Width (ft)	Median Width (ft)	LTL Width (ft)	Curb Offset (ft)	Medial Separator Width (ft)	LTL Width (ft)	Curb Offset (ft)	Medial Separator Width (ft)	Thru-Lane Separator Width (ft)	LTL Width (ft)	Curb Offset (ft)	Medial Separator Width (ft)	Offset to Opposing LTL (ft)	Thru-Lane Separator Width (ft)	LTL Width (ft)	Curb Offset (ft)	Medial Separator Width (ft)	Offset to Opposing LTL (ft)
4	4																
6	6																
8	8	NOT FEASIBLE						NOT FEASIBLE					NOT FEASIBLE				
10	10																
12	12				NOT FEASIBLE												
14	14	10	2	2													
16	16	10	2	4				2	10	2	2	0					
18	18	12	2	4				4	10	2	2	2	2	10	2	4	−2
20	20	12	2	6				6	10	2	2	4	4	10	2	4	0
22	22	12	2	8				7	10	2	3	4	6	10	2	4	2
24	24	12	2	10	10	2	2	7	12	2	3	4	6	12	2	4	2
26	26	12	2	12	10	2	4	8	12	2	4	4	8	12	2	4	4
28	28	12	2	14	11	2	4	9	12	2	5	4	10	12	2	4	6
30	30	12	2	16	12	2	4	10	12	2	6	4	12	12	2	4	8
32	32	12	2	18	12	2	6	11	12	2	7	4	14	12	2	4	10
34	34	12	2	20	12	2	8	12	12	2	8	4	16	12	2	4	12
36	36	12	2	22	12	2	10	13	12	2	9	4	18	12	2	4	14
38	38	12	2	24	12	2	12	14	12	2	10	4	20	12	2	4	16
40	40	12	2	26	12	2	14	15	12	2	11	4	22	12	2	4	18
42	42	12	2	28	12	2	16	16	12	2	12	4	24	12	2	4	20
44	44	12	2	30	12	2	18	17	12	2	13	4	26	12	2	4	22
46	46	12	2	32	12	2	20	18	12	2	14	4	28	12	2	4	24
48	48	12	2	34	12	2	22	19	12	2	15	4	30	12	2	4	26
50	50	12	2	36	12	2	24	20	12	2	16	4	32	12	2	4	28
52	52	12	2	38	12	2	26	21	12	2	17	4	34	12	2	4	30
54	54	12	2	40	12	2	28	22	12	2	18	4	36	12	2	4	32
56	56	12	2	42	12	2	30	23	12	2	19	4	38	12	2	4	34
58	58	12	2	44	12	2	32	24	12	2	20	4	40	12	2	4	36
60	60	12	2	46	12	2	34	25	12	2	21	4	42	12	2	4	38
62	62	12	2	48	12	2	36	26	12	2	22	4	44	12	2	4	40
64	64	12	2	50	12	2	38	27	12	2	23	4	46	12	2	4	42
66	66	12	2	52	12	2	40	28	12	2	24	4	48	12	2	4	44
68	68	12	2	54	12	2	42	29	12	2	25	4	50	12	2	4	46
70	70	12	2	56	12	2	44	30	12	2	26	4	52	12	2	4	48
72	72	12	2	58	12	2	46	31	12	2	27	4	54	12	2	4	50
74	74	12	2	60	12	2	48	32	12	2	28	4	56	12	2	4	52
76	76	12	2	62	12	2	50	33	12	2	29	4	58	12	2	4	54
78	78	12	2	64	12	2	52	34	12	2	30	4	60	12	2	4	56
80	80	12	2	66	12	2	54	35	12	2	31	4	62	12	2	4	58
82	82	12	2	68	12	2	56	36	12	2	32	4	64	12	2	4	60
84	84	12	2	70	12	2	58	37	12	2	33	4	66	12	2	4	62

KEY TO SHADING:

- Not Feasible
- Marginal
- Feasible

NOTE: LTL = Left-Turn Lane

This table applies only to intersections with raised or depressed medians
LTLs could be used in narrower median widths if a flush median were used.

parallel, offset left-turn lanes; and tapered, offset left-turn lanes. Table 25 summarizes the ranges of median width for which these left-turn treatments are feasible, marginal, or not feasible for intersections with raised or depressed medians.

Tables 24 and 25 are based on the following assumptions:

1. In accordance with the Green Book, the minimum median width considered is 1.2 m (4 ft).
2. The maximum median width tabulated is 26 m (84 ft), which is the largest desirable width for a median on a rural divided highway indicated by any of the highway agencies that responded to the survey conducted during the research.
3. Left-turn lanes had a desirable width of 3.6 m (12 ft), plus a 0.6-m (2-ft) curb offset. Minimum left-turn lane widths of 3.1 m (10 ft), plus a 0.6-m (2-ft) curb offset, were used where necessary in narrow medians, but such designs were classified as marginal in Tables 24 and 25. Where there is a curb on one side of a left-turn lane, a curb offset of 0.6 m (2 ft) is assumed. Where there is a curb on both sides of a left-turn lane, a total curb offset of 0.6 m (2 ft) is assumed; it could be 0.3 m (1 ft) on each side of the left-turn lane or 0.6 m (2 ft) on the median side and no offset on the side toward the through lanes (assuming a mountable curb is used on that side).
4. At locations where the median is wide enough to accommodate a double left-turn lane, it is also wide enough to accommodate a restricted median opening at an unsignalized location (i.e., left off the major road only, left onto the major road only, U-turn only).
5. For parallel, offset left-turn lanes, the medial separator between the left-turn lane and the adjacent through lane (in the same direction of travel) has a desirable width of 1.2 m (4 ft) or more. A minimum separator width of 0.6 m (2 ft) was used where necessary in narrow medians, but such designs were classified as marginal in Tables 24 and 25. Parallel, offset left-turn lanes with lane widths of less than 3.6 m (12 ft) or offsets to the opposing left-turn lane of less than 1.2 m (4 ft) were also classified as marginal.
6. Parallel, offset left-turn lanes were aligned to have an offset of +1.2 m (+4 ft) or more, whenever possible, on the basis of the offset criteria defined in Appendix F.
7. Tapered, offset left-turn lanes were aligned to intersect the median roadway with a 1.2-m (4-ft) separator from the opposing through lanes. Thus, the angle of the tapered left-turn lanes varies as a function of median width. The widths of the medial and through-lane separators shown in Table 24 are measured along the median roadway; these dimensions change as one moves upstream, away from the median roadway. Tapered, offset left-turn lanes with lane widths of less than 3.6 m (12 ft) or offsets to the opposing left-turn lane of less than 1.2 m (4 ft) were classified as marginal in Tables 24 and 25.

Each specific left-turn treatment is discussed later in this chapter.

TABLE 24. **Feasible allocations of available width for various median widths and left-turn treatments (cont.)**

	No LTL	Single Left-Turn Lane			Double Left-Turn Lanes			Parallel Offset Left-Turn Lane					Tapered Offset Left-Turn Lane				
Median Width (m)	Median Width (m)	LTL Width (m)	Curb Offset (m)	Medial Separator Width (m)	LTL Width (m)	Curb Offset (m)	Medial Separator Width (m)	Thru-Lane Separator Width (m)	LTL Width (m)	Curb Offset (m)	Medial Separator Width (m)	Offset to Opposing LTL (m)	Thru-Lane Separator Width (m)	LTL Width (m)	Curb Offset (m)	Medial Separator Width (m)	Offset to Opposing LTL (m)
1.2	1.2	NOT FEASIBLE			NOT FEASIBLE			NOT FEASIBLE					NOT FEASIBLE				
1.5	1.5																
1.8	1.8																
2.1	2.1																
2.4	2.4																
2.7	2.7																
3.0	3.0																
3.3	3.3																
3.6	3.6																
3.9	3.9																
4.2	4.2	3.0	0.6	0.6													
4.5	4.5	3.0	0.6	0.9													
4.8	4.8	3.0	0.6	1.2				0.6	3.0	0.6	0.6	0.0					
5.1	5.1	3.6	0.6	0.9				0.9	3.0	0.6	0.6	0.3					
5.4	5.4	3.6	0.6	1.2				1.2	3.0	0.6	0.6	0.6					
5.7	5.7	3.6	0.6	1.5				1.3	3.0	0.6	0.8	0.6	0.9	3.0	0.6	1.2	−0.3
6.0	6.0	3.6	0.6	1.8				1.3	3.3	0.6	0.8	0.6	1.2	3.0	0.6	1.2	0.0
6.3	6.3	3.6	0.6	2.1				1.5	3.3	0.6	0.9	0.6	1.5	3.0	0.6	1.2	0.3
6.6	6.6	3.6	0.6	2.4				1.8	3.3	0.6	0.9	0.9	1.5	3.3	0.6	1.2	0.3
6.9	6.9	3.6	0.6	2.7				1.8	3.6	0.6	0.9	0.9	1.8	3.3	0.6	1.2	0.6
7.2	7.2	3.6	0.6	3.0	3.0	0.6	0.6	2.1	3.6	0.6	0.9	1.2	1.8	3.6	0.6	1.2	0.6
7.5	7.5	3.6	0.6	3.3	3.0	0.6	0.9	2.2	3.6	0.6	1.1	1.2	2.1	3.6	0.6	1.2	0.9
7.8	7.8	3.6	0.6	3.6	3.0	0.6	1.2	2.4	3.6	0.6	1.2	1.2	2.4	3.6	0.6	1.2	1.2
8.1	8.1	3.6	0.6	3.9	3.3	0.6	0.9	2.5	3.6	0.6	1.3	1.2	2.7	3.6	0.6	1.2	1.5
8.4	8.4	3.6	0.6	4.2	3.3	0.6	1.2	2.7	3.6	0.6	1.5	1.2	3.0	3.6	0.6	1.2	1.8
8.7	8.7	3.6	0.6	4.5	3.6	0.6	0.9	2.8	3.6	0.6	1.6	1.2	3.3	3.6	0.6	1.2	2.1
9.0	9.0	3.6	0.6	4.8	3.6	0.6	1.2	3.0	3.6	0.6	1.8	1.2	3.6	3.6	0.6	1.2	2.4
9.3	9.3	3.6	0.6	5.1	3.6	0.6	1.5	3.2	3.6	0.6	1.9	1.2	3.9	3.6	0.6	1.2	2.7
9.6	9.6	3.6	0.6	5.4	3.6	0.6	1.8	3.3	3.6	0.6	2.1	1.2	4.2	3.6	0.6	1.2	3.0
9.9	9.9	3.6	0.6	5.7	3.6	0.6	2.1	3.5	3.6	0.6	2.2	1.2	4.5	3.6	0.6	1.2	3.3
10.2	10.2	3.6	0.6	6.0	3.6	0.6	2.4	3.6	3.6	0.6	2.4	1.2	4.8	3.6	0.6	1.2	3.6
10.5	10.5	3.6	0.6	6.3	3.6	0.6	2.7	3.8	3.6	0.6	2.5	1.2	5.1	3.6	0.6	1.2	3.9
10.8	10.8	3.6	0.6	6.6	3.6	0.6	3.0	3.9	3.6	0.6	2.7	1.2	5.4	3.6	0.6	1.2	4.2
11.1	11.1	3.6	0.6	6.9	3.6	0.6	3.3	4.1	3.6	0.6	2.8	1.2	5.7	3.6	0.6	1.2	4.5
11.4	11.4	3.6	0.6	7.2	3.6	0.6	3.6	4.2	3.6	0.6	3.0	1.2	6.0	3.6	0.6	1.2	4.8
11.7	11.7	3.6	0.6	7.5	3.6	0.6	3.9	4.4	3.6	0.6	3.1	1.2	6.3	3.6	0.6	1.2	5.1
12.0	12.0	3.6	0.6	7.8	3.6	0.6	4.2	4.5	3.6	0.6	3.3	1.2	6.6	3.6	0.6	1.2	5.4
12.3	12.3	3.6	0.6	8.1	3.6	0.6	4.5	4.7	3.6	0.6	3.4	1.2	6.9	3.6	0.6	1.2	5.7
12.6	12.6	3.6	0.6	8.4	3.6	0.6	4.8	4.8	3.6	0.6	3.6	1.2	7.2	3.6	0.6	1.2	6.0
12.9	12.9	3.6	0.6	8.7	3.6	0.6	5.1	5.0	3.6	0.6	3.7	1.2	7.5	3.6	0.6	1.2	6.3
13.2	13.2	3.6	0.6	9.0	3.6	0.6	5.4	5.1	3.6	0.6	3.9	1.2	7.8	3.6	0.6	1.2	6.6
13.5	13.5	3.6	0.6	9.3	3.6	0.6	5.7	5.3	3.6	0.6	4.0	1.2	8.1	3.6	0.6	1.2	6.9
13.8	13.8	3.6	0.6	9.6	3.6	0.6	6.0	5.4	3.6	0.6	4.2	1.2	8.4	3.6	0.6	1.2	7.2
14.1	14.1	3.6	0.6	9.9	3.6	0.6	6.3	5.6	3.6	0.6	4.4	1.2	8.7	3.6	0.6	1.2	7.5
14.4	14.4	3.6	0.6	10.2	3.6	0.6	6.6	5.7	3.6	0.6	4.5	1.2	9.0	3.6	0.6	1.2	7.8
14.7	14.7	3.6	0.6	10.5	3.6	0.6	6.9	5.9	3.6	0.6	4.7	1.2	9.3	3.6	0.6	1.2	8.1
15.0	15.0	3.6	0.6	10.8	3.6	0.6	7.2	6.0	3.6	0.6	4.8	1.2	9.6	3.6	0.6	1.2	8.4
15.3	15.3	3.6	0.6	11.1	3.6	0.6	7.5	6.2	3.6	0.6	5.0	1.2	9.9	3.6	0.6	1.2	8.7
15.6	15.6	3.6	0.6	11.4	3.6	0.6	7.8	6.3	3.6	0.6	5.1	1.2	10.2	3.6	0.6	1.2	9.0
15.9	15.9	3.6	0.6	11.7	3.6	0.6	8.1	6.5	3.6	0.6	5.3	1.2	10.5	3.6	0.6	1.2	9.3
16.2	16.2	3.6	0.6	12.0	3.6	0.6	8.4	6.6	3.6	0.6	5.4	1.2	10.8	3.6	0.6	1.2	9.6

KEY TO SHADING:

- Not Feasible
- Marginal
- Feasible

NOTE: LTL = Left-Turn Lane

This table applies only to intersections with raised or depressed medians
LTLs could be used in narrower median widths if a flush median were used.

GUIDELINES FOR SELECTING MEDIAN WIDTHS AT DIVIDED HIGHWAY INTERSECTIONS

The following section presents recommended guidelines for selecting median widths at divided highway intersections. The design policy presented in the AASHTO Green Book specifies a minimum width of 1.2 m (4 ft) for highway medians. Most medians are wider than this, and the guidelines presented below explain the factors to be considered in selecting the median width for divided highway intersections.

Rural Intersections

The key finding presented in Chapter 2 of this report concerning rural intersections is that accident rates at rural, four-leg, unsignalized intersections decrease as the median width increases. This finding is supported by the results of the field observational studies, which found that the frequency of undesirable driving behavior at rural, four-leg, unsignalized intersections also decreases as the median width increases. Rural, three-leg, unsignalized intersections were found to have very low accident rates, and no statistically significant relationships were found between median width and accident rate or undesirable driving behavior. Although this indicates that traffic operational or safety problems are much less likely at three-leg than at four-leg intersections, it is recommended that the design guidelines based on the findings concerning rural, four-leg intersections also be applied to rural, three-leg intersections.

The following guidelines are recommended for selecting the median width at rural, unsignalized intersections on divided highways:

1. At rural, unsignalized intersections on divided highways, wider medians generally operate more safely than narrow medians. On the basis of traffic operational and safety considerations alone, the median at each rural intersection should be as wide as possible. In selecting median widths, however, highway agencies must also consider right of way and construction costs, the potential for driver confusion and wrong-way movements, the desirability of uniform design for particular corridors and within particular roadway functional classifications, and the potential for traffic volume growth and development.
2. Two key factors in selecting the median width at rural

TABLE 25. Feasible left-turn treatments for various median widths

Median Width (ft)	No Left–Turn Lane	Single Left–Turn Lane	Double Left–Turn Lane	Parallel Offset Left–Turn Lane	Tapered Offset Left–Turn Lane
4	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
6	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
8	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
10	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
12	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
14	FEASIBLE	MARGINAL	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
16	FEASIBLE	MARGINAL	NOT FEASIBLE	MARGINAL	NOT FEASIBLE
18	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
20	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
22	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
24	FEASIBLE	FEASIBLE	MARGINAL	MARGINAL	MARGINAL
26	FEASIBLE	FEASIBLE	MARGINAL	FEASIBLE	FEASIBLE
28	FEASIBLE	FEASIBLE	MARGINAL	FEASIBLE	FEASIBLE
30	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
32	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
34	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
36	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
38	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
40 and over	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE

Median Width (m)	No Left–Turn Lane	Single Left–Turn Lane	Double Left–Turn Lane	Parallel Offset Left–Turn Lane	Tapered Offset Left–Turn Lane
1.2	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
1.8	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
2.4	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
3.0	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
3.6	FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
4.2	FEASIBLE	MARGINAL	NOT FEASIBLE	NOT FEASIBLE	NOT FEASIBLE
4.8	FEASIBLE	MARGINAL	NOT FEASIBLE	MARGINAL	NOT FEASIBLE
5.4	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
6.0	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
6.6	FEASIBLE	FEASIBLE	NOT FEASIBLE	MARGINAL	MARGINAL
7.2	FEASIBLE	FEASIBLE	MARGINAL	MARGINAL	MARGINAL
7.8	FEASIBLE	FEASIBLE	MARGINAL	FEASIBLE	FEASIBLE
8.4	FEASIBLE	FEASIBLE	MARGINAL	FEASIBLE	FEASIBLE
9.0	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
9.6	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
10.2	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
10.8	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
11.4	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE
12.0 and over	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE	FEASIBLE

intersections are the appropriate design vehicle for turning and crossing maneuvers at the intersection and the type of left-turn treatment to be implemented.

An important step in designing a divided highway intersection is to select an appropriate design vehicle for turning and crossing maneuvers at the intersection. This design vehicle normally should be determined from consideration of the current and design year traffic composition and characteristics of the crossroad, which may be quite different from the composition and characteristics of traffic on the major road. The demand for U-turns is another factor in determining the design vehicle; if a divided highway has driveways used by larger vehicles at which median openings are not provided, larger vehicles find it necessary to make U-turns at other intersections or median openings to go to or from those driveways. Thus, at some intersections, the design vehicle for turning and crossing maneuvers may be based on U-turn demands rather than crossroad traffic

volume or mix. The median width requirements for different left-turn treatments have been addressed in the previous section.

3. The minimum median width at intersections on a rural divided highway generally should be 8 m (25 ft). This median width allows storage of the 6-m (19-ft) AASHTO passenger car design vehicle with 0.9 m (3 ft) of clearance to through traffic at each end of the vehicle. Medians less than 8 m (25 ft) wide generally should be used in rural areas only where wider medians are infeasible or, at existing intersections, where narrower medians are already in place and are operating without major traffic operational or safety problems.
4. At many rural divided highway intersections, the crossroad carries only minimal heavy truck traffic. At such locations, many highway agencies have chosen the school bus as the appropriate design vehicle. The maximum length of school buses in use is approximately 12 m (40 ft). With 0.9-m (3-ft) clearance to the through lanes at each end of the vehicle, a 14-m (46-ft) median width is appropriate for storing a school bus. For this reason, many highway agencies use divided highway median widths in the range of 14 to 15 m (46 to 50 ft).
5. Where a large truck is used as the design vehicle, a median 21 to 31 m (70 to 100 ft) wide generally should be selected.
6. When a median width greater than 24 to 31 m (80 to 100 ft) is used at a divided highway intersection, designers should recognize the potential for wrong-way movements if crossroad drivers fail to see both roadways of the divided highway and to recognize the divided highway as such. Signing should also be effective in helping crossroad drivers recognize the major road as a divided highway. A subsequent section of this chapter addresses methods to minimize wrong-way movements.
7. The leading cause of undesirable driving behavior at unsignalized intersections is the competition for limited space in the median roadway by vehicles making turning and crossing maneuvers. As turning and crossing volumes increase, more space on the median roadway is needed and wider medians may be appropriate.
8. Although traffic operational and safety research indicates that rural, unsignalized intersections generally should have medians as wide as possible, designers generally should avoid wide medians if the location is likely to undergo suburban development or to be signalized within the foreseeable future. As discussed below, wider medians lead to higher accident rates and undesirable driving behavior at suburban, unsignalized intersections. Thus, designers should avoid creating intersections that might develop traffic operational or safety problems if they become more developed. In addition, highway agencies have found that intersections with wider medians are difficult to signalize properly. The design guidelines for suburban intersections, presented below, may be applicable to such cases.
9. Increased ISD is required at divided highway intersections where the median is not wide enough to store a turning or crossing vehicle. If the intersection is wide enough to store a turning or crossing vehicle, the sight distance requirements at the intersection of the median roadway with the far roadway of the divided highway are the same as at any other intersection.
10. Median opening lengths at rural divided highway intersections generally should be kept to the minimum possible. This issue is addressed further in the subsequent section on design and marking the median roadway.

In summary, the research results tend to confirm the practice of most states to provide rural medians with widths in the range of 14 to 18 m (46 to 60 ft). Such medians are wide enough that one school bus or two passenger cars making a turning or crossing maneuver can be stored on the median roadway. Medians narrower than 14 m (46 ft) are adequate to store a passenger car (or two smaller passenger cars) but may not be adequate to store the largest school bus. Medians wider than 18 m (60 ft) provide very safe operations at rural intersections and may be particularly appropriate at locations with substantial volumes of large trucks making turning and crossing maneuvers; however, highway agencies should consider limiting the use of wider medians at intersections that may require signalization or may undergo suburban development in the foreseeable future.

As stated above, the choice of an appropriate design vehicle for turning and crossing maneuvers on the basis of crossroad and U-turn traffic mix is a key step in selecting the appropriate median width for a divided highway intersection. Site-specific traffic analyses may lead, however, to the choice of different design vehicles and, therefore, different minimum median widths at intersections along a given divided highway corridor. Consistency in median width along such corridors is highly desirable because consistency in design improves driver expectancy of geometric features. Thus, the practice of using a consistent median width along a corridor, on the basis of the largest design vehicle for turning and crossing maneuvers for any of the intersections in the corridor, should be encouraged. Even if this practice results in medians that are wider than required at some intersections, it is not generally a problem because accident rates have been found to decrease with increasing median widths. The only locations at which this corridor-based approach to median width selection may not be desirable are intersections that are considered likely to require signalization or undergo suburban development in the future.

Field observations have found that vehicles making opposing left-turns tend to turn in front of one another if the median is less than 15 m (50 ft) wide and tend to turn behind one another if the median is more than 15 m (50 ft) wide. It may be undesirable to mix intersections with median widths that are less than and more than 15 m (50 ft) within the same corridor, because driver behavior at such intersections differs.

Consistency can also be achieved by using a standard median width on a statewide basis for all rural divided highways. This may improve driver expectancy of median widths even more than adopting a consistent median width for a specific corridor. Each intersection, however, should be reviewed in the design process to determine if a change in the standard median width would be appropriate. Medians that are wider than the standard may be appropriate at some intersections with large volumes of turning or crossing truck traffic, and medians that are narrower than the standard may be appropriate where future signalization or suburban development is expected.

Some highway agencies have started to implement a new practice of widening their standard 14 to 18 m (46 to 60 ft) median to 46 m (150 ft) or more at selected higher-volume intersections. This practice is new and largely untested but may

contribute to safety because rural intersections with medians more than 31 m (100 ft) wide are known to operate very safely. Because this approach results in varying median width along a corridor, methods of changing driver expectancy by calling particular attention to the intersections with wider medians are desirable. For example, extensive use of advance guide signs for the intersections with wider medians might provide a cue to approaching drivers that these wider median intersections are somehow different from the rest. Particular attention also needs to be paid to signing for crossroad drivers to help ensure that they recognize the major road as a divided highway; such signing is critical to discourage wrong-way movements.

Suburban Unsignalized Intersections

The key research finding concerning suburban, unsignalized intersections is that the frequency of accidents and undesirable driving behavior increases as the median width increases. Medians clearly add to the safety and efficiency of traffic operations on suburban highways; however, the research finding stated above implies that, where medians are provided on suburban highways, the median widths at unsignalized intersections should be kept as narrow as possible. The following design guidelines are applicable to suburban unsignalized intersections:

1. 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. Most suburban intersections have left-turn lanes, which generally require minimum widths of 4 to 5 m (14 to 18 ft) for raised medians.
2. Many highway agencies prefer to use medians between 4.2 and 7.2 m (14 and 24 ft) wide on suburban highways because they are wide enough to provide left-turn lanes but are not wide enough to store a crossing or turning vehicle in the median. Median widths in this range require through and left-turn vehicles on the crossroad approach to wait for simultaneous gaps in both directions of travel on the major road before completing their turning or crossing maneuver. This philosophy is consistent with keeping the median width as narrow as possible. It should be recognized, however, that the sight distance requirements for turning and crossing vehicles are higher for divided highway intersections of this type than for intersections on undivided highways.
3. Medians wider than 7.6 m (25 ft) may be used at intersections on suburban highways, but designers should anticipate that crossroad vehicles making turning and crossing maneuvers will stop on the median roadway, if necessary. The length of the design vehicle(s) to be accommodated and the demand for storage space on the median roadway should be considered in selecting the median width. Designers should avoid making the median wider than necessary, because accidents and undesirable driving behavior increase as median width increases and because, if the intersection requires signalization in the future, total delay will increase as median width increases (see next section of this chapter).
4. Some unsignalized intersections have experienced safety problems because vehicles waiting to turn left from the major road block the view of opposing left-turn or crossroad vehicles, which can lead to collisions between major-road through vehicles and vehicles leaving the median roadway to cross the through lanes. Appendix F presents a method for computing the offset required between opposing left-turn lanes and the minimum left-turn lane length needed to minimize such problems. Parallel or tapered offset left-turn lanes can be used at unsignalized intersections to provide increased sight distance, although such treatments are less common than at signalized intersections; offset left-turn lanes generally increase the required median width at the intersection.
5. Medians with widths of more than 15 m (50 ft) generally should be avoided at suburban, unsignalized intersections, both because they could be expected to have higher accident rates and because driver confusion could result from opposing left-turn drivers turning behind one another, rather than turning in front of one another as they do at most other suburban intersections.

In summary, medians at suburban, unsignalized intersections should generally be narrower than those used in rural areas because narrower medians generally result in safer operations at suburban intersections and because narrower medians will result in more efficient operations if the intersection requires signalization at a later date. The minimum median width in suburban areas generally should be set by the width requirements of the left-turn treatment to be used. Increased ISD may be required if the median is not wide enough to store a turning or crossing vehicle. Consistency in median width along a divided highway corridor is desirable; achieving consistency may require considering appropriate median widths for both signalized and unsignalized intersections.

Suburban Signalized Intersections

The research findings reported in Chapter 2 indicate that the accident rate at suburban, signalized intersections increases as the median width increases. In addition, the increased clearance times required by wider medians increase traffic delays at the signalized intersections and can, therefore, reduce the level of service. The following design guidelines are applicable to suburban, signalized intersections:

1. Median widths at suburban, signalized intersections generally should be as narrow as possible while providing sufficient space in the median for the appropriate left-turn treatment. A variety of left-turn treatments are potentially applicable at signalized intersections, including conventional left-turn lanes, double left-turn lanes, and parallel and tapered offset left-turn lanes. The median width requirements of these left-turn treatments have been presented earlier in this chapter.
2. Suburban signalized intersections can generally operate effectively with median widths of less than 7.6 m (25 ft) because there should be no need for crossroad traffic to stop on the median roadway except during the crossroad green phase. It is undesirable for turning or crossing vehicles from a crossroad approach to remain in the median during the major-road green phase; clearance intervals are generally provided in the signal cycle so that crossroad vehicles are not trapped in the median after the signal turns red. Medians

wider than 7.6 m (25 ft) are not generally recommended at suburban, signalized intersections unless required for the selected left-turn treatment.

3. Signalized intersections with median widths of more than 18 m (60 ft) are difficult to signalize effectively so that vehicles are not trapped in the median at the end of the crossroad green phase. Some highway agencies have found it necessary to install detectors on the median roadway to delay the beginning of the major-road green phase until all crossroad vehicles have cleared the median roadway.
4. When intersections with median widths of greater than 31 m (100 ft) are signalized, it may be necessary to provide separate signals at each intersection of the median roadway with the through lanes of the divided highway. This type of signalization, which is equivalent to the signal system used at a diamond interchange, often involves greater delay than the use of a single signal; however, the total delay to through vehicles decreases as the median width increases and, at some relatively large median width, eventually becomes less than the delay at a single signal for that same median width. Diamond-type signal systems also require careful attention to the storage requirements on the median roadway, which may be exceeded if the traffic volumes are too high or the median width is too small. Wide medians that require diamond-type signalization generally should be avoided but may be necessary in some circumstances such as staged freeway construction in which frontage roads are built first and the freeway is constructed between them at a later date.
5. Some signalized intersections have experienced safety problems because vehicles waiting to turn left from the major road block the view of opposing left-turn or crossroad vehicles, which can lead to collisions between major-road through vehicles and vehicles leaving the median roadway to cross the through lanes. Appendix F presents a method for computing the offset required between opposing left-turn lanes and the minimum left-turn lane length needed to minimize such problems. The required offset can be provided by either parallel or tapered offset left-turn lanes, which generally increase the required median width at the intersection.

In summary, the median widths at suburban, signalized intersections should be as narrow as possible but are largely determined by the type of left-turn treatment to be used. Left-turn treatments anticipated for future use (e.g., double left-turn lanes) should also be considered in determining the median width. Consistency in median width along a divided highway corridor is desirable; achieving consistency may require consideration of appropriate median widths for both signalized and unsignalized intersections.

DESIGN AND MARKING OF THE MEDIAN ROADWAY TO MINIMIZE UNDESIRABLE DRIVING BEHAVIOR

Several types of undesirable driving behavior, including side-by-side queuing, angle stopping, and encroaching on the through lanes of the major road, were observed in field studies at divided highway intersections. The results of the field observational studies, however, suggest methods that can be used to minimize such undesirable driving behavior.

The field study results indicate that the undesirable driving behavior is often related to the competition for limited space on the median roadway between vehicles traveling through the median in the same direction. Thus, undesirable driving behavior is likely to increase as the median volume increases. Traffic volumes are generally not high enough at most rural intersections to lead to operational problems, but such problems have been observed at particular sites. Traffic volumes using the median roadway are likely to be higher at suburban intersections. Where the median volume is high and the available storage space on the median roadway is inadequate, several alternatives should be considered, including the following:

- Increasing the median width or median opening length to provide more storage space. The choice between increasing the median width and the median opening length is addressed below.
- Reducing the median width to 7.2 m (24 ft) or less so that there is not enough room in the median to store a vehicle, and crossing and turning vehicles from the crossroad approaches must wait for simultaneous gaps. This alternative is generally more applicable to suburban intersections than to rural intersections, where wider medians are desirable for safety.
- Closing the median opening and permitting only right turns in and right turns out of the crossroad.
- Reducing the median volume through turn prohibitions or channelization to eliminate particular traffic movements through the median. For example, Figure 36 shows how channelization can be used to permit left turns off a divided highway while preventing crossing maneuvers and left turns onto the divided highway.
- Signalizing the intersection to separate conflicting traffic movements in time. If the median width is narrow enough to permit the installation of a single signal, then vehicles from the crossroad approaches should not need to be stored in the median during the major-road green phase; however, signalization should be considered only where the MUTCD signal warrants are met and where signalization can be accomplished without interfering with signal progression on the major road.

One of the accepted principles of intersection channelization (*10*) is that large, uninterrupted expanses of pavement within an intersection can be confusing to drivers and should be avoided. The presence of a large expanse of pavement makes it difficult for drivers to decide what path to follow and to anticipate what path other drivers will follow. It is generally better for both traffic operations and safety to channelize an intersection and guide drivers along specific paths. For this reason, it is not desirable to provide additional storage space on the median roadway by increasing both the median width and median opening length, as that would create a large unrestricted pavement area like that discussed above. It is better to increase the median width or increase the median opening length but not both. The research findings indicate that at rural, unsignalized intersections, it is better to increase the median width and keep the median opening length to a minimum consistent with the width of the crossroad roadway and shoulders. At suburban, unsignalized intersections, the research findings indicate that it is generally more desirable to keep the median width to a minimum and increase the median opening length; at many higher-volume

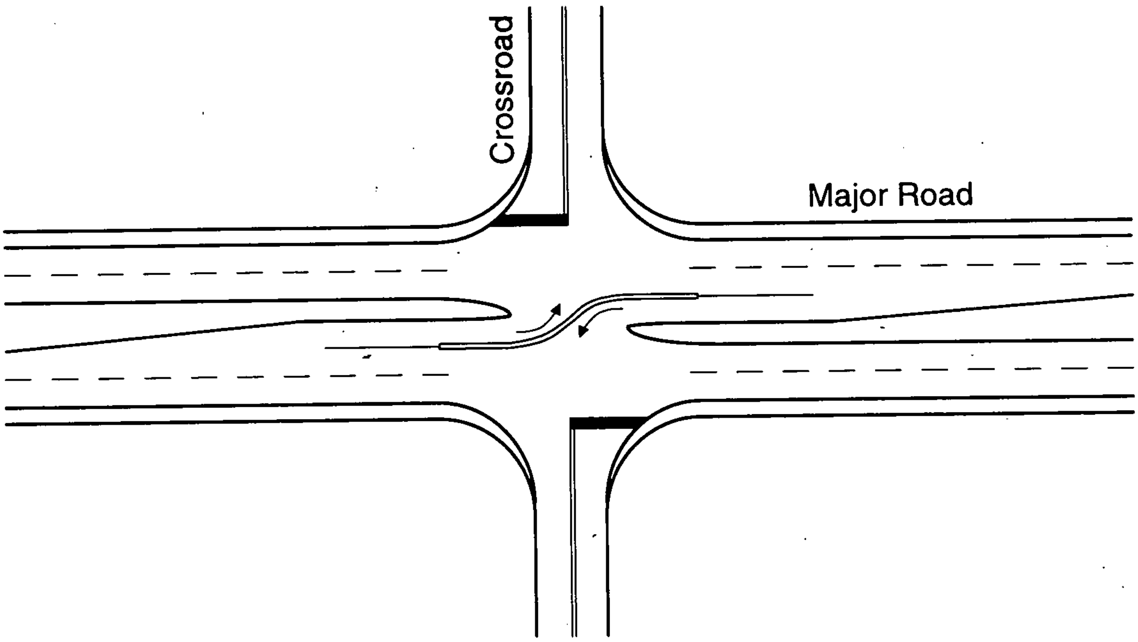


Figure 36. Median channelization to prevent movements through the median except left turns off the divided highway.

intersections, an increased median opening length will occur naturally because of multiple lanes and/or wider shoulders on the crossroad, but median openings should not be made unnecessarily long because this may result in undesirable side-by-side queuing.

Pavement markings can be very useful in helping to define vehicle paths at divided highway intersections. At rural, unsignalized intersections with median widths of more than 31 m (100 ft), it is highly desirable to provide a double yellow centerline separating the two directions of travel on the median roadway. This type of marking, illustrated in Figure 37, provides visual continuity with the centerline of the crossroad approaches and helps to define a desired path for drivers. For example, by creating a relatively narrow marked path through the median roadway, the presence of a double yellow centerline on the median roadway should minimize the temptation for drivers to queue side-by-side or to cut over to the left side of the median roadway and stop at an angle when making a left turn. The three sites evaluated in the field studies, with medians more than 31 m (100 ft) wide and with markings of this type, had among the lowest rates of accidents and undesirable driving behavior of any of the intersections studied.

The AASHTO Green Book generally recommends a minimum median opening length of 12 m (40 ft). In fact, two of the intersections studied with median widths of more than 31 m (100 ft) had median opening lengths in the range of 30 to 40 ft (9 to 12 m) and operated very safely. If the minimum median opening length recommended by the Green Book is used at such a wide-median intersection, the use of edge lines to delineate a portion of the median roadway as a shoulder might be considered, to define the path for vehicles across the median to be as much like a normal lane as possible.

At unsignalized intersections with median widths of approximately 18 m (60 ft) or less, dashed pavement markings that extend the left edge line of the divided highway across the intersection can also be helpful to drivers. Such markings, illustrated in Figure 38, define the boundaries of the median roadway for drivers and should help to minimize encroachment on the through lanes of the divided highway by vehicles stopped on the median roadway. This practice has been used satisfactorily by at least two of the state highway agencies that participated in the study.

DESIGN GUIDELINES FOR OTHER GEOMETRIC AND TRAFFIC CONTROL FEATURES OF INTERSECTIONS

This section presents design guidelines for left-turn lanes, offset left-turn lanes, indirect left-turn lanes, U-turn treatments, median acceleration lanes, traffic control on the median roadway, wrong-way movements, and pedestrian considerations.

Left-Turn Lanes

The need for left-turn lanes is one factor that influences the choice of median width. Tables 24 and 25 show the ranges of median width for which conventional single and double left-turn lanes are feasible.

Two alternative policies for installation of left-turn lanes on divided highways have been used by highway agencies:

• Provide left-turn lanes where specific warrants, such as those presented in Figure 6, indicate they are needed

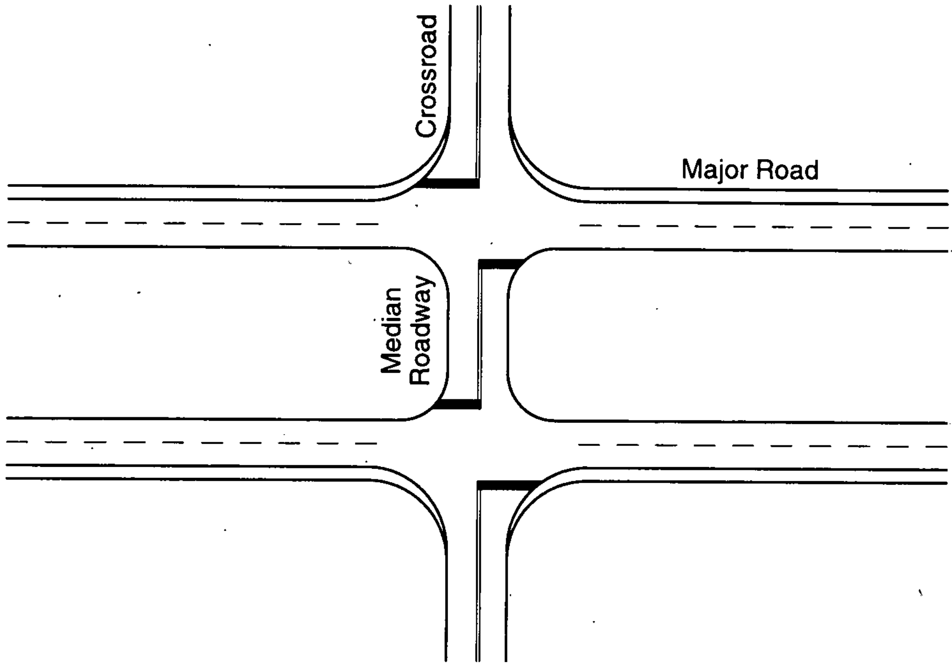


Figure 37. Recommended marking of the median roadway at a wide-median intersection with a two-lane crossroad.

• Provide left-turn lanes at all median openings where left turns are permitted

The first alternative is consistent with the Green Book and has, historically, been the policy of most highway agencies; however, several highway agencies have adopted the second policy in recent years, at least in designing rural divided highways.

Current practice in designing left-turn lanes at divided highway intersections is presented in Figure 5.

Offset Left-Turn Lanes

Parallel and tapered offset left-turn lanes like those shown in Figure 8 are still not common but are being used increasingly to reduce the risk of accidents caused by the sight obstructions from opposing vehicles turning left. The survey results in Appendix A indicate that 62 percent of state highway agencies and 42 percent of local highway agencies have used offset left-turn lanes. There are no national design guidelines for offset left-turn lanes. Parallel offset left-turn lanes are mentioned only briefly in the Green Book, and tapered offset left-turn lanes are not mentioned at all. Tables 24 and 25 show the ranges of median width for which parallel and tapered offset left-turn lanes are feasible.

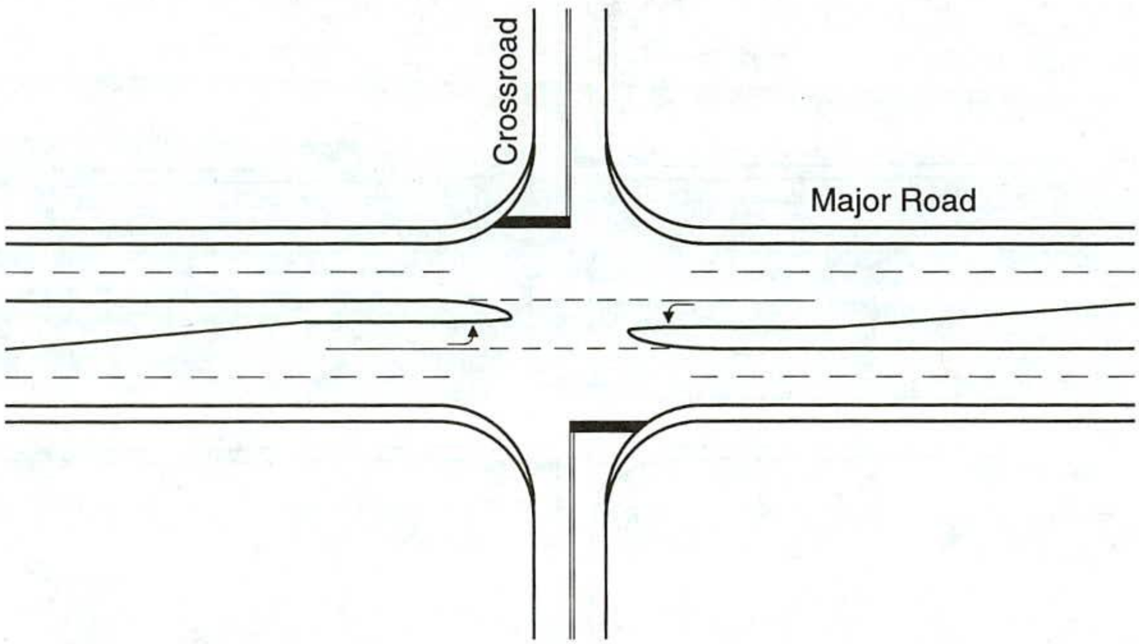
There are no generally accepted warrants for offset left-turn lanes and no guidelines for choosing between the parallel and tapered designs. The criteria for installing offset left-turn lanes used by one state highway agency are presented in Chapter 2, following the discussion of Figure 8. The research performed in this study found that most drivers use offset left-turn lanes properly, although a few problems were observed. The research, however, does not provide a basis for selecting any particular left-turn lane design as superior. Advance signing and pavement markings at the entrance to the left-turn lane can assist drivers in recognizing offset left-turn lanes. Lighting of intersections with offset left-turn lanes should be considered, whenever possible, to assist left-turning drivers to recognize the proper path at night.

Indirect Left-Turn Lanes

Indirect left-turn lanes like those shown in Figure 10 have an important role in enabling drivers to make left turns efficiently on divided highways with relatively narrow medians. Two state highway agencies—the Michigan and New Jersey Departments of Transportation—have used indirect left-turn treatments extensively and drivers in those states understand and expect them. Other highway agencies have used indirect left-turn treatments less frequently. An important advantage of indirect left-turn lanes is that they may allow a divided highway to operate with a narrower median than would be required if left-turn lanes were placed in the median.

U-Turn Treatments

The current Green Book policy on median width requirements at U-turn median openings has been presented in Figure 11 in Chapter 2 of this report. This policy shows the median width requirements for U-turns from the inner lane (leftmost travel lane) in one direction of travel to the inner lane, outer lane, and shoulder in the opposite direction of travel. This same policy could be applied to determine the median width requirements for U-turns at intersections. Because many intersections have left-turn lanes within the median area, it may be appropriate to



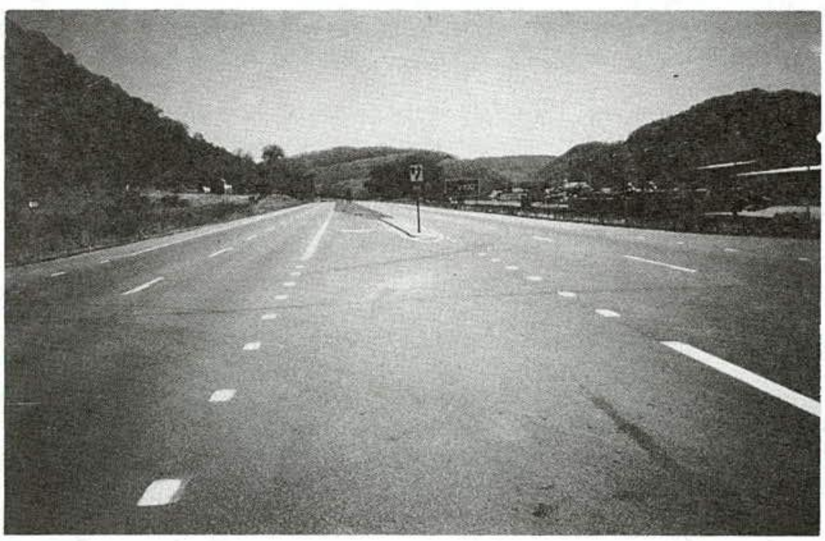


Figure 38. Extending edgelines across the median to better define the boundaries of the median roadway.

include, as well, the median width requirements for U-turns from a median left-turn lane to the inner lane, outer lane, and shoulder in the opposing direction of travel.

Median Acceleration Lanes

Median acceleration lanes, like offset left-turn lanes, have come into use at divided highway intersections in recent years but have been used by only a few agencies. A typical median acceleration lane is shown in Figure 9. The advantage of median acceleration lanes is that they allow vehicles turning left onto a divided highway to continue through the median roadway without stopping and merge onto the far roadway of the divided highway. That allows drivers to cross the near roadway of the divided highway without considering the availability of gaps on the far roadway, even if the median is not wide enough to store their vehicles; however, even if a median acceleration lane is provided, left-turning drivers must anticipate potential conflicts with other vehicles in the median area. Thus, the presence of a median acceleration lane changes the decision making process and the maneuvers made by crossroad drivers turning left onto

the divided highway, but not by drivers crossing the divided highway. The median acceleration lane should be long enough to allow left-turning vehicles to reach the speed of major-road traffic before merging.

Traffic Control on the Median Roadway

Highway agencies currently use Stop signs, Yield signs, and no control at the intersection of the median roadway and the far roadway of a divided highway. At unsignalized intersections with medians less than 9 m (30 ft) wide, highway agencies quite consistently use no control on the median roadway, as specified in the MUTCD. For unsignalized intersections with median widths of 26 m (85 ft) or more, highway agencies are quite consistent in using Stop signs at the intersection of the median roadway and the far roadway of a divided highway. For intersections with median widths between 9 and 26 m (30 and 85 ft), Stop signs, Yield signs, and no control are all used by highway agencies. Even within a given state, more than one type of control was observed with this intermediate range of median widths.

Field observations found that less than 50 percent of drivers complied fully (i.e., made a complete stop) with Stop signs on the median roadway. The remaining drivers either made a rolling stop or did not stop at all. On the other hand, no traffic conflicts resulted from vehicles violating the Stop signs, and most of the drivers could have stopped if a conflicting vehicle were present. In short, most drivers treated the Stop sign as if it were a Yield sign. The use of Stop signs in this situation may be detrimental because traffic control devices are not desirable in situations in which they are ignored.

The field observational study found no discernable differences in driver behavior at intersections with Yield signs or no control.

On the basis of the field studies conducted in the research, the following traffic control policy for divided highway intersections appears to be appropriate:

1. For intersections with median widths of less than 9 m (30 ft), use no control on the median roadway as specified in the MUTCD.
2. For intersections with median widths between 9 and 26 m (30 and 85 ft), use either Yield signs or no control on the median roadway. Either Yield signs or no control should be used consistently to help in developing driver expectancy. Stop signs should be used only if an intersection develops a record of accidents involving vehicles crossing or turning into the far roadway of the divided highway.
3. For intersections with median widths of 26 m (85 ft) or more, Stop signs should be used on the median roadway.

Some traffic control device is definitely needed at such wide-median intersections to help drivers perceive the presence of the far roadway of the divided highway. Stop signs are recommended because they are used quite universally for this application; however, there is reason to believe that Yield signs, used consistently, could function equally well.

Wrong-Way Movements

Careful attention should be given to minimizing the potential for wrong-way movements at divided highway intersections, because driver errors of this type can lead to severe accidents. Wrong-way movements are a particular concern at intersections with wider medians, particularly when the median is more than 24 to 31 m (80 to 100 ft) wide, because it may not be apparent to all crossroad drivers that the major road is a divided highway. The following design and traffic control guidelines are applicable:

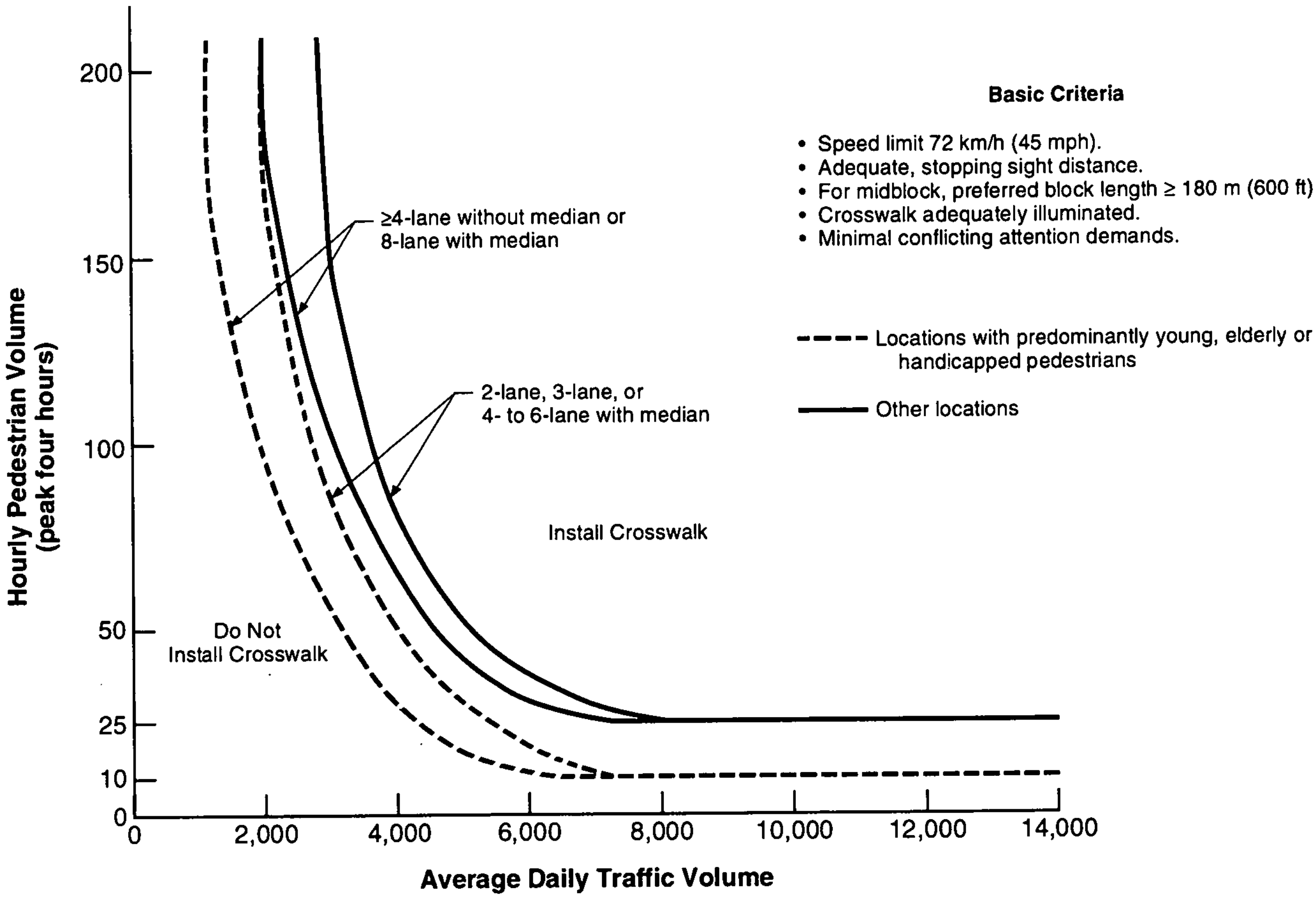
1. Provide signing to help drivers on the crossroad approaches recognize that left turns into the near roadway of the divided highway are not permitted. This may include One-Way signs, No Left Turn signs, Wrong-Way signs, and Divided Highway plaques.
2. Whenever possible, drivers on the crossroad approaches should be able to see both roadways of the divided highway. Clearing sight obstructions in the median that limit the view of the far roadway should be considered. The view of the traffic control device at the far end of the median roadway (Stop sign or Yield sign) may provide an important cue that the driver has reached a divided highway intersection.
3. Where the crossroad approaches the divided highway on a downgrade, the driver is afforded the best view of the entire intersection. Where the crossroad approaches the divided highway on an upgrade, drivers may have a poor view of the intersection, and special care in designing other geometric features and signing may be needed.
4. Whenever possible, divided highway intersections with wider medians should be lighted at night to assist drivers in seeing both sides of the major road and recognizing it as a divided highway.
5. Whenever possible, angles of intersection other than 90 degrees, as well as unusual intersection layouts, should be avoided.

Pedestrian Considerations

The following design guidelines, based on the work of Knoblauch et al. (*55*) are recommended for pedestrian facilities at divided highway intersections:

Basic Criteria

1. Crosswalks should not be marked where crossing the street may be unusually hazardous (e.g., locations with high traffic speeds, poor sight distance, or poor illumination; locations with inadequate median refuge space; or locations with insufficient pedestrian crossing time in the traffic signal cycle).
2. In light of the installation and maintenance costs of pavement markings, crosswalk markings should be located at places expected to receive sufficient benefit. This suggests that crosswalks with low vehicular volume and/or low pedestrian volume do not warrant markings. Determining minimum pedestrian and vehicle volume thresholds is an important part of establishing reasonable guidelines for crosswalk markings.
3. Guidelines for installing crosswalks should include the type of pedestrians expected to be crossing the street. Lower-



1. If using only the peak hour, threshold must be increased by 1.5.
2. For streets with median, use one-way (directional) ADT volume.

Other notes: Minimum striping is 150-mm (6-in) lines. Consider bolder markings and/or supplementary advance markings or signing at uncontrolled locations where speed limits exceed 55 km/h (35 mph).

Figure 39. Guidelines for crosswalk installation at uncontrolled intersection legs, midblock crossings, and signalized intersections without pedestrian heads (55).

volume thresholds should be considered for areas where there is a greater proportion of less experienced and less agile pedestrians (e.g., near schools and/or elderly housing areas).

4. Crosswalk markings in higher-risk crossing areas (higher traffic volumes and speeds) should be supplemented by warning signs at the crossing and before the crossing, and in some cases, warning pavement markings.
5. Crosswalks should be used selectively. Allowing a proliferation of crosswalks reduces the overall effectiveness of each crosswalk.
6. Specific variables that should be considered when locating crosswalks include activities located nearby (e.g., schools, shopping), pedestrian volume, vehicular volume, sight distance, vehicular speeds, street width, presence and width of median refuge area, corner radii and turning roadway channelization, one-way versus two-way operation, and the feasibility of providing the necessary pedestrian crossing time in the traffic signal cycle.

Installation Guidelines

Crosswalk markings should be installed at the following:

• All signalized intersections with pedestrian signal heads

• All locations where a school crossing guard is normally stationed to assist children in crossing the street

• All intersections and midblock crossings satisfying the minimum vehicular and pedestrian volume criteria in Figure 39 (As long as the basic criteria governing sight distance, speed limit, and so forth are met, a crosswalk is deemed appropriate if the pedestrian and vehicular volumes place it above the appropriate curve in Figure 39. Each crosswalk is analyzed by approach leg, indicating that a crosswalk might be warranted on one side of the intersection and not the other. Thus, the guidelines might suggest that only one crosswalk needs to be marked at a given intersection. If each approach warranted a crosswalk, then all would be marked.)

• All other locations where there is a need to clarify the

preferred crossing location when the proper location for crossing would otherwise be confusing.

RECOMMENDED REVISIONS TO THE AASHTO GREEN BOOK

Recommended revisions to the AASHTO Green Book to implement the findings of this research are presented in Appendix G. The recommended revisions include modifications to Chapter IV (Cross Section Elements), Chapter VII (Rural and Urban Arterials), and Chapter IX (At-Grade Intersections). These recommendations will be considered by the AASHTO Task Force on Geometric Design, which is responsible for determining what changes to the Green Book are appropriate.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of the research are as follows:

1. At rural, unsignalized intersections, the frequency of both accidents and undesirable driving behavior (e.g., side-by-side queuing, angle stopping, and encroaching on the through lanes of the major road) decreases as the median width increases.
2. At suburban, unsignalized intersections, the frequency of both accidents and undesirable driving behavior increases as the median width increases.
3. At suburban, signalized intersections, the frequency of accidents increases as the median width increases.
4. 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.
5. 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.
6. Compliance with Stop signs at the intersection between the median roadway and the far roadway of a divided highway is poor. Less than 50 percent of drivers make a full stop, but very few traffic conflicts between median roadway and major-road vehicles result. In fact, drivers tend to operate similarly at the intersection between the median roadway and the far roadway of a divided highway—regardless of the type of traffic control used—Stop sign, Yield sign, or no control.
7. Vehicle delay at signalized intersections on divided highways increases as the median width increases. Thus, increasing the median width at a signalized intersection reduces the level of service. This finding is based on traffic simulation analyses for traffic volumes of up to 1,000 veh/hr on each major-road approach and up to 800 veh/hr on each crossroad approach; left- and right-turn percentages of up to 30 percent on each major-road approach and of up to 40 percent on each crossroad approach; and for median widths of 6 to 31 m (20 to 100 ft).
8. Signalized intersections on divided highways with medians wider than 31 m (100 ft) may require separate signal installations on the two roadways of the divided highway. This type of signalization operates similarly to the signalization at a diamond interchange. Using separate signal installations substantially increases vehicle delay, which substantially reduces level of service, in comparison with a single signal installation serving the same approach volumes and turning movement patterns. Therefore, signalized intersections with wide medians should be avoided, where possible, on the grounds of operational efficiency. Where diamond-type signalization must be used, however, the vehicle delay for any given traffic volume level decreases, and the space available for storing vehicles on the median roadway increases as the median width increases. Thus, if a median wide enough to require diamond-type signalization is necessary, increasing the median width further should improve the level of service.
9. Divided highway intersections with medians that are not wide enough to store a vehicle safely in the median require more ISD for crossing and left-turn maneuvers than similar intersections on undivided highways. Where vehicles can stop safely in the median, however, the sight distance requirements of divided highway intersections are similar to undivided highway intersections.
10. Tapered and parallel offset left-turn lanes can be used at divided highway intersections to minimize or eliminate sight distance obstructions caused by opposing left-turn vehicles. No major traffic operational or safety problems were found at three signalized intersections with offset left-turn lanes that were evaluated in the research.

The following recommendations have been developed on the basis of these conclusions:

1. At rural, unsignalized intersections on divided highways, medians should generally be as wide as practical and certainly should be wide enough to accommodate turning and crossing maneuvers by a selected design vehicle, as well as any needed left-turn treatments. In most cases, the appropriate design vehicle for rural, unsignalized intersections is a large school bus or a large truck. Whenever possible, the median opening length should be limited to the crossroad pavement width plus shoulders, to better define the turning paths and avoid making the paved area in the median too large.
2. At suburban, unsignalized intersections, medians generally should not be wider than necessary to provide whatever left-turn treatment is selected. Wider medians at suburban, unsignalized intersections are associated with increased accident frequency. 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.
3. At signalized intersections, medians generally should not be wider than necessary to provide whatever left-turn treatment is selected. Wider medians at signalized intersections are

associated with increased accident frequency and increased delay.

4. Highway agencies should consider limiting median widths at rural, unsignalized intersections that are likely to require signalization or undergo suburban development in the foreseeable future. Wider medians should operate well at a rural, unsignalized intersection but may operate poorly if the intersection becomes signalized and/or undergoes development.
5. At rural, unsignalized intersections with median widths of more than 31 m (100 ft), the use of a double yellow centerline to separate the two directions of travel on the median roadway is recommended.
6. At unsignalized intersections with median widths of approximately 18 m (60 ft) or less, dashed pavement markings that extend the left edgeline of the divided highway across the intersection can be helpful to drivers in defining the boundaries of the median roadway. Markings of this type should help to minimize encroachment on the through lanes of the divided highway by vehicles stopped on the median roadway.
7. The following recommendations are applicable to traffic control within unsignalized divided highway intersections at the intersection of the median roadway with the far roadway of the divided highway:
   a. For intersections with median widths of less than 9 m (30 ft), use no control on the median roadway as specified in the MUTCD.
   b. For intersections with median widths between 9 and 26 m (30 and 85 ft), use either Yield control or no control on the median roadway. Stop signs should be used only if an intersection develops a record of accidents involving vehicles crossing or turning into the far roadway of the divided highway.
   c. For intersections with median widths of 26 m (85 ft) or more, Stop signs should be used on the median roadway.
8. Particular care should be taken in designing and operating wide-median intersections to ensure that the intersection is properly signed to discourage improper left turns into the near roadway of the divided highway and that, whenever possible, a driver on the crossroad approach to a divided highway intersection can see the far roadway of the divided highway. Both signing and visibility of the far roadway help to discourage wrong-way movements that can lead to accidents. Such intersections should be lighted at night, whenever possible. Wrong-way movements were not found in this research to be a major problem, but the potential for accidents involving wrong-way movements always exists at divided highway intersections.

REFERENCES

1. *A Policy on Geometric Design of Highways and Streets.* American Association of State Highway and Transportation Officials, Washington, D.C.(1994).
2. *A Policy on Geometric Design of Highways and Streets.* American Association of State Highway and Transportation Officials, Washington, D.C. (1990).
3. *TRB Special Report 209: Highway Capacity Manual,* 3rd ed. TRB, National Research Council, Washington, D.C. (1994).
4. Wallace, C.E., Chang, E.C.P., Messer, C.J., and Courage, K.G. *PASSER II-90 Users Guide.* Texas A&M University, College Station (December 1991).
5. Fambro, D.B., Chaudhary, N.A., Bonneson, J.A., Messer, C.J., and Arabie, L.J. *PASSER III-90 User Manual.* Texas A&M University, College Station (March 1991).
6. Lee, C.E., Rious, T.W., and Copeland, C.R. *The Texas Model for Intersection Traffic—Development.* Center for Highway Research, Austin, TX (December 1977).
7. Lee, C.E., Machemehl, R.B., Rious, T.W., and Inman, R.F. *Texas Model Version Documentation.* Center for Transportation Research, Bureau of Engineering Research, University of Texas (August 1991).
8. *Roadside Design Guide.* American Association of State Highway and Transportation Officials, Washington, D.C. (1989).
9. Bonneson, J.A., McCoy, P.T., and Truby, J.E. "Safety Improvements at Intersections on Rural Expressways: A Survey of State Departments of Transportation." In *Transportation Research Record 1385,* TRB, National Research Council, Washington, D.C. (1993).
10. Neuman, T.R. *NCHRP Report 279: Intersection Channelization Design Guide.* TRB, National Research Council, Washington, D.C. (November 1985).
11. Harmelink, M.D. "Volume Warrants for Left-Turn Storage Lanes at Unsignalized Grade Intersections." In *Highway Research Record 211,* HRB, National Research Council, Washington, D.C. (1967).
12. *Effectiveness of Median Storage and Acceleration Lanes for Left-Turning Vehicles.* Institute of Transportation Engineers, Informational Report (1986).
13. *Traffic Engineering Evaluation: U.S. 60 Intersections, Mesa to Apache Junction, MP 189.0-196.0.* Arizona Department of Transportation, Traffic Engineering Section, Traffic Studies Branch (undated).
14. *1991 Accident Data on California State Highways (Road Miles, Travel, Accidents, Accident Rates).* California Department of Transportation (1992).
15. Harwood, D.W., Mason, J.M., and Graham, J.L. *Conceptual Plan for an Interactive Highway Design Model.* Draft report prepared for Contract No. DTFH61-91-C-00091, Midwest Research Institute, Kansas City, MO (June 1992).
16. McDonald, J.W. "Relation Between Number of Accidents and Traffic Volume at Divided-Highway Intersections." *Bulletin 74,* HRB, National Research Council, Washington, D.C. (1953).
17. Priest, R.V. "Statistical Relationships Between Traffic Volume, Median Width, and Accident Frequency on Divided Highway Grade Intersections." *Highway Research News,* No. 13, HRB, National Research Council, Washington, D.C. (June 1964).
18. Hurd, F.W. "Accident Experience with Traversable Medians of Different Widths." *Bulletin 137,* HRB, National Research Council, Washington, D.C. (1956).
19. Moskowitz, K., and Schaefer, W.E. "California Median Study: 1958." *Bulletin 266,* HRB, National Research Council, Washington, D.C. (1960).
20. Hutchinson, J.W., and Kennedy, T.W. "Safety Considerations in Median Design." In *Highway Research Record 162,* HRB, National Research Council, Washington, D.C. (1967).
21. Garner, G., and Deen, R.C. "Elements of Median Design in Relation to Accident Occurrence." In *Highway Research Record 432,* HRB, National Research Council, Washington, D.C. (1973).
22. Foody, T.J., and Culp, T.B. "A Comparison of the Safety Potential of the Raised versus Depressed Median Design." In *Transportation Research Record 514,* TRB, National Research Council, Washington, D.C. (1974).
23. Knuiman, M.W., Council, F.M., and Reinfurt, D.W. "The Effect of Median Width on Highway Accident Rates." Presented at the 72nd Annual Meeting of the Transportation Research Board, Washington, D.C. (January 1993).
24. Van Maren, P.A. "Correlation of Design and Control Characteristics with Accidents at Rural Multilane Highway Intersections in Indiana." *Report No. FHWA/IN-77/20,* Joint Highway Research Project, Purdue University, West Lafayette, IN (December 1977) (revised July 1980).
25. Radwan, A.E., Sinha, K.C., and Michael, H.L. "Development and Use of a Computer Simulation Model for the Evaluation of Design and Control Alternatives for Intersections of Minor Roads with Multilane Rural Highways: Selection of the Simulation Model." *Report No. FHWA-IN-79-8,* Joint Highway Research Project, Purdue University, West Lafayette, IN (July 1979).
26. Radwan, A.E., Sinha, K.C., and Michael, H.L. "Development and Use of a Computer Simulation Model for the Evaluation of Design and Control Alternatives for Intersections of Minor Roads with Multilane Rural Highways: Field Studies and Model Validation." *Report No. FHWA/IN-79/9,* Joint Highway Research Project, Purdue University, West Lafayette, IN (July 1979).
27. Radwan, A.E., Sinha, K.C., and Michael, H.L. "Development and Use of a Computer Simulation Model for the Evaluation of Design and Control Alternatives for Intersections of Minor Roads with Multilane Rural Highways: Model Application." *Report No. FHWA/IN-79/10,* Joint Highway Research Project, Purdue University, West Lafayette, IN (July 1979).
28. *Manual on Uniform Traffic Control Devices for Streets and Highways.* Federal Highway Administration, Washington, D.C. (1988).
29. *Manual on Uniform Traffic Control Devices for Streets and Highways.* Federal Highway Administration, Washington, D.C. (1978).

30. Briglia, P.M. "4-Way Stop Signs Cut Accident Rate 58 Percent at Rural Intersections." *ITE Journal* (November 1984).
31. Agent, K.R. *Traffic Control and Accidents at Rural, High-Speed Intersections*. Kentucky Transportation Research Program, University of Kentucky, Lexington (March 1987).
32. Eck, R.W., and Sabra, Z.A. "Active Advance Warning Signs at High-Speed Signalized Intersections: A Survey of Practice." In *Transportation Research Record 1010*, TRB, National Research Council, Washington, D.C. (1985).
33. Foody, T.J., and Taylor, W.C. "An Analysis of Flashing Systems." In *Highway Research Record 221*, HRB, National Research Council, Washington, D.C. (1968).
34. Goldblatt, R.B. "Effect of Flashing Beacons on Intersection Performance." In *Transportation Research Record 644*, TRB, National Research Council, Washington, D.C. (1977).
35. McCoy, P.T., Navarro, U.R., and Witt, W.E. "Guidelines for Offsetting Opposing Left-Turn Lanes on Four-Lane Divided Roadways." In *Transportation Research Record 1356*, TRB, National Research Council, Washington, D.C. (1992).
36. Wickens, C.D. *Engineering Psychology and Human Performance*. Charles E. Merrill Publishing Company, Columbus, OH (1984).
37. Boff, K.R., and Lincoln, J.E. *Engineering Data Compendium: Human Perception and Performance*. AAMRL, Wright-Patterson AFB, OH (1988).
38. Fambro, D.B., Fitzpatrick, K., Griffin, L.I., Kahl, K.B., Koppa, R.J., and Petzold, V.J. "Determination of Stopping Sight Distances." *Interim Report for NCHRP Project 3-42*, Texas Transportation Institute, College Station, TX (December 1992).
39. Olson, P.L., Cleveland, D.E., Fancher, P.S., Kostyniuk, L.P., and Schneider, L.W. *NCHRP Report 270: Parameters Affecting Stopping Sight Distance*. TRB, National Research Council, Washington, D.C. (1984).
40. Hall, J.W., and Turner, D.S. "Stopping Sight Distance: Can We See Where We Now Stand?" In *Transportation Research Record 1208*, TRB, National Research Council, Washington, D.C. (1989).
41. Rackoff, N.J., and Rockwell, T.H. "Driver Search and Scan Patterns in Night Driving." In *TRB Special Report 156: Driver Visual Needs in Night Driving*, TRB, National Research Council, Washington, D.C. (1975).
42. Staplin, L., Lococo, K., and Sim, J. "Traffic Control Design Elements to Accommodate Drivers With Diminished Capability." *Report FHWA-RD-90/055*, Federal Highway Administration, Washington, D.C. (May 1990).
43. Dewar, R., Templar, J., and Knoblauch, R. "An Analysis of the Older Pedestrian's Task and Related Motor, Sensory, Perceptual, Cognitive, and Behavioral Factors." Task A report for the study *Older Pedestrian Characteristics for Use in Highway Design*, Center for Applied Research, Great Falls, VA (1992).
44. Shinar, D., and Scheiber, F. "Visual Requirements for Safety and Mobility of Older Drivers." *Human Factors* (1991).
45. Salthouse, T.A. "Speed of Behavior and Its Implications for Cognition." In *Handbook of the Psychology of Aging* (J.E. Binen and K.W. Schaie, eds.), Van Nostrand Reinhold, NY (1985).
46. Lerner, N., et al. "Older Driver Perception-Reaction Time for Intersection Sight Distance and Object Detection." *Report No. FHWA-RD-93-168*, Federal Highway Administration, Washington, D.C. (January 1995).
47. Lerner, N. "Giving the Older Driver Enough Perception-Reaction Time." *Experimental Aging Research*, Vol. 20 (1994).
48. *TRB Special Report 218: Transportation in an Aging Society*. TRB, National Research Council, Washington, D.C. (1988).
49. Hunter-Zaworski, K.M. "T-Intersection Simulator Performance of Drivers with Physical Limitations." In *Transportation Research Record 1281*, TRB, National Research Council, Washington, D.C. (1990).
50. Scifres, P.N. "Wrong-Way Movements on Divided Highways." *Report No. JHRP-74-3*, Joint Highway Research Project, Purdue University, West Lafayette, IN (February 1974).
51. Tamburri, T.N. "Wrong-Way Driving Accidents Are Reduced." In *Highway Research Record 292*, HRB, National Research Council, Washington, D.C. (1969).
52. Mills, J.P. "Wrong-Way Driving in Virginia." Paper presented at the 1972 Summer Meeting of the AASHO Operating Subcommittee on Traffic Engineering (cited in Reference 50).
53. Messer, C.J., Friebele, J.D., and Dudek, C.L. "A Quantitative Analysis of Wrong-Way Driving in Texas." *Research Report 139-6*, Texas Transportation Institute, College Station, TX (May 1971) (cited in Reference 50).
54. Estep, A.C. "Wrong-Way Driving on California Freeways 1961-1972." Paper presented at the 1972 Summer Meeting of the AASHO Operating Subcommittee on Traffic Engineering (cited in Reference 50).
55. Knoblauch, R.L., Tustin, B., Smith, S.A., and Pietrucha, M.T. *Investigation of Exposure Based Pedestrian Accident Areas*. Federal Highway Administration, Washington, D.C. (November 1986).
56. *Parking Dimensions of 1990 Model Passenger Cars*. Motor Vehicle Manufacturers Association, Washington, DC (1990).
57. *SAS/STAT User's Guide*, Version 6, 4th ed. SAS Institute, Inc., Gary, NC (1990).
58. McShane, W.R., and Roess, R.P. *Traffic Engineering*. Prentice Hall, Englewood Cliffs, NJ (1990).
59. Joshua, S.C., and Saka, A.A. "Mitigation of Sight-Distance Problem for Unprotected Left-Turning Traffic at Intersections." In *Transportation Research Record 1356*, TRB, National Research Council, Washington, D.C. (1992).

APPENDIXES A–F

Appendixes A through F as submitted by the research agency are not published herein but are available for loan on request to the NCHRP.

APPENDIX A Summary of Questionnaire Responses from State and Local Highway Agencies

APPENDIX B Field Observational Studies at Divided Highway Intersections

APPENDIX C Evaluation of Accident Histories at Field Study Sites

APPENDIX D Evaluation of Statewide Accident Data for Divided Highway Intersections

APPENDIX E Effect of Median Width on Traffic Operations at Signalized Intersections

APPENDIX F Sight Distance Implications of Offsetting Left-Turn Lanes at Divided Highway Intersections

APPENDIX G

RECOMMENDED REVISIONS TO THE AASHTO GREEN BOOK

This appendix presents recommended revisions to the design policies in the AASHTO publication, *A Policy on Geometric Design of Highways and Streets*, known as the AASHTO Green Book (*1*). The Green Book is the primary geometric design guide used by many highway agencies and other geometric design practitioners.

The recommended revisions are based on the findings of this research and, other than a few minor editorial suggestions, do not address issues other than median width at intersections on divided highways. Sections of the Green Book potentially affected by the research findings include portions of Chapter IV (Cross Section Elements), Chapter VII (Rural and Urban Arterials), and Chapter IX (At-Grade Intersections). The remainder of the appendix presents the current text of the Green Book with recommended changes. Deletions of text are shown as ~~strikeouts~~ and additions to the text are shown in **bold**.

The Green Book text presented in this appendix is based on the 1994 edition of the Green Book that, for the first time, incorporates units in the SI or metric system.

GREEN BOOK CHAPTER IV (Cross Section Elements)

The following text shows the recommended revisions to the section on medians that appears in pages 367-369 in Chapter IV of the 1994 Green Book. The recommended changes are intended primarily to incorporate the research findings that wider medians are desirable at rural intersections but not at urban or suburban intersections or at intersections that may require signalization.

MEDIANS

A median is highly desirable on arterials carrying four or more lanes. A median is defined as the portion of a divided highway separating the traveled way for traffic in opposing directions. The median width is expressed as the dimension between the through-lane edges and includes the left shoulders, if any. The principal functions of a median are to separate opposing traffic, provide a recovery area for out-of-control vehicles, provide a stopping area in case of emergencies, allow space for speed changes and storage of left-turning and U-turning vehicles, minimize headlight glare, and provide width for future lanes. Another benefit of a median in an urban area is that it may offer an open green space. For maximum efficiency, a median should be highly visible both night and day and contrast with the though traffic lanes. Medians may be depressed, raised, or flush with the pavement surface. ~~Medians should be as wide as feasible but of a dimension in balance with other components of the cross section.~~

In determining median width, consideration should be given to the possible need for median barrier. Where possible, median widths should be such that a median barrier is not warranted. ~~In general, the median should be as wide as practical.~~ The general range of median widths is from a minimum of 1.2 m to 24 m or more. Economic factors often limit the width of median that can be provided. Cost of construction and maintenance increases in proportion to increases in the median width but the additional cost may not be appreciable compared with the cost of the highway as a whole and may be justified in view of the benefits derived.

At unsignalized intersections on divided highways in rural areas, the median should generally be as wide as practical. However, narrower medians appear to operate better at unsignalized intersections in urban and suburban areas; therefore, wider medians should be avoided in urban and suburban areas except where necessary to accommodate turning and crossing maneuvers by larger vehicles [reference this report]. Medians **at unsignalized intersections** should be wide enough to allow selected design vehicles to safely make a selected maneuver. **The appropriate design vehicle should be chosen based on the actual or anticipated vehicle mix of crossroad and U-turn traffic.** A consideration in the use of wider medians on roadways other than freeways is the provision of adequate shelter for vehicles crossing at **unsignalized** intersections and at crossovers serving commercial and private drives. These median crossings may need to be controlled as at-grade intersections (See Chapter IX). Wide medians may be a disadvantage when ~~at-grade intersections are~~ **signalization is** required. The increased time for vehicles to cross the median ~~may~~ **can** lead to inefficient signal operation.

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

A depressed median is generally preferred on freeways for more efficient drainage and snow removal. Median side slopes should preferably be 1:6, but slopes of 1:4 may be adequate. All drainage inlets in the median should at least be designed with the top flush with the ground or culvert ends provided with traversable safety grates.

Raised medians have application on arterial streets where it is desirable to regulate left-turn movements. They are also frequently used where the median is to be planted, particularly where the width is relatively narrow. Careful consideration of the location and type of plantings must be given. Plantings, particularly in narrow medians, may create problems for maintenance activities. Plantings, such as trees, in the median can also cause visual obstructions for turning motorists if not carefully located.

Flush medians are **commonly** used ~~to some extent~~ on ~~all types of~~ urban arterials. When used on freeways, a median barrier may be required. The median should be slightly crowned or depressed for drainage. In warmer climates the crowned type is frequently used because it eliminates the need for collecting drainage water in the median. However, the slightly depressed type is generally preferred with a cross slope of about 4 percent or with a minor steepening of the roadway cross slope.

The concept of converting flush medians into two-way left turn lanes on urban streets has become widely accepted. This concept offers several advantages when compared to no median. Among the advantages are reduced travel time, improved capacity, reduced accident frequency, particularly of the rear-end type, more flexibility because the median lane can be used as a travel lane during closure of a through lane and public preference, both from drivers and owners of abutting properties. Median widths **of** 3.0 to 4.8 m ~~wide~~ provide the optimum design for two-way left turn lanes. Refer to the MUTCD (*2*) for appropriate lane markings. Refer to Chapter II for additional discussion and details.

Where there is no fixed-source lighting, headlight glare across medians or outer separations can be a nuisance, particularly where the highway has relatively sharp curves. Under these conditions, some form of antiglare treatment should be considered as part of the median barrier installation, provided it does not act as a snow fence and create drifting problems.

Insofar as through traffic is concerned, a desired ease and freedom of operation, in the sense of physical and psychological separation from opposing traffic, is obtained when medians are about 72 m or wider. With such widths the facility truly is divided. The noise and air pressure of opposing traffic is not noticeable, and at night the glare of headlights is greatly reduced. With widths of 18 m or more the median can be pleasingly landscaped in a parklike manner. Plantings used to achieve this parklike appearance ~~should~~ **need** not compromise the roadside recovery area. ~~It must be pointed out, however, that~~ There is demonstrated benefit in any separation, raised or ~~flushed~~ **flush. Wider medians are desirable at rural unsignalized intersections, but medians as wide as 18 m may not be desirable at urban and suburban intersections or at intersections that are signalized or may require signalization in the foreseeable future [reference this report].**

GREEN BOOK CHAPTER VII (Rural and Urban Arterials)

The following text shows the recommended revisions to the discussion of medians in the section on rural arterials on pages 498 and 499 in Chapter VII of the 1994 Green Book. The primary intent of these changes is to incorporate the research findings on median widths at rural, unsignalized intersections along with caveats for intersections that may become signalized or may undergo suburban development.

Medians

On highways without at grade intersections, the median may be as narrow as 1.2 to 1.8 m under very restricted conditions but ~~a width of 20 m or more~~ **wider medians** should be provided wherever feasible. A wide median allows the use of independent profiles. Reduced frequency of crossover accidents and reduction of headlight glare are safety features associated with a wide median.

When intersections are to be provided, special concern must be given to the width of the median. **Research has shown that most types of undesirable driving behavior on the median roadway of divided highway intersections are associated with competition for space on the median roadway by vehicles traveling in the same direction through the median [reference this report]. The potential for such problems is limited where crossroad and U-turn volumes are low but may increase at higher volumes. Types of undesirable driving behavior observed include side-by-side queuing, angle stopping, and encroaching on the through lanes of the divided highway. At rural unsignalized intersections, the frequency of undesirable driving behavior and the frequency of accidents were observed to decrease as the median width increased; that implies that the median width should be as wide as practical. It was also observed that the frequency of undesirable driving behavior increased as the median opening length increased.**

While medians as narrow as 1.2 to 1.8 m may be ~~required~~ **necessary** under very restricted conditions, medians 3.6 to 9 m wide provide protection for left-turning vehicles at intersections. ~~Median widths from 9 to 15 m should be carefully considered from an operational standpoint at intersections. These widths do not provide median storage space for larger vehicles crossing the median. Also, these widths may encourage the driver to attempt the crossings independently leaving a portion of the vehicle unprotected from through traffic. These widths, even with these problems normally operate quite well and apparently are within the realm of normal operational expectations of the driver. Widths in the range of 15 to 24 m have developed accident problems in some areas as the drivers apparently tend to become confused about the intended operational characteristics of the multiple intersections encountered. Medians wide enough to assure the driver that the intersection with the two sets of lanes operate separately have worked quite well. Research may prove that wider medians are not desirable for some facilities with at-grade intersections.~~ **In many cases, the median width at a rural unsignalized intersection will be a function of the design vehicle selected for turning and crossing maneuvers. Where a median width of 7.6 m or more is provided, a passenger car making a turning or crossing maneuver will have space to stop safely in the median area. Medians less than 7.6 m wide should be avoided at rural intersections because drivers may be tempted to stop in the median with part of their vehicles unprotected from through**

traffic. Many highway agencies use the school bus as the design vehicle to determine the median width at rural divided highway intersections; the school bus is often the largest vehicle to use the median roadway frequently. The selection of a school bus as the design vehicle results in a median width of 14 to 15 m. Larger design vehicles, including trucks, may be used at intersections where enough turning or crossing trucks are present; median widths of 23 m or more may be needed to accommodate large tractor-trailer trucks without encroaching on the through lanes of the major road.

There was concern that median widths in the range of 15 to 24 m at divided highway intersections could cause some drivers to become confused. Recent research has not found any evidence of such confusion at rural intersections [reference this report]. However, an intersection with a wider median may become confusing to some drivers if the median is so wide that a driver on the crossroad approach cannot see the far roadway of the divided highway. Such designs should be avoided and, where necessary, signing should be used to discourage wrong-way movements.

Median widths of more than 18 m are undesirable at intersections that are signalized or may require signalization in the foreseeable future. The efficiency of signal operations decreases as the median width increases, because drivers require more time to traverse the median and special detectors may be needed to avoid trapping drivers in the median at the end of the green phase for traffic movements that pass through the median. Furthermore, if the median is so wide that separate signals are required on the two roadways of the divided highway, delays to motorists will increase substantially and careful attention must be given to vehicle storage requirements on the median roadway between the two signals.

The subsequent section concerning median widths at intersections on urban arterials indicates that wider medians may increase accidents and lead to undesirable driving behavior. Therefore, highway agencies may wish to limit the use of wider medians at rural intersections that are likely to undergo urban or suburban development in the foreseeable future.

Research also indicates that undesirable driving behavior at rural unsignalized intersections increases as the median opening length increases [reference this report]. The median opening length should be equal to at least the minimum described in Chapter IX, but median openings at rural unsignalized intersections should not be unnecessarily long.

See Chapter IV for information on median design.

The following text presents the recommended changes to the section concerning medians on urban arterials on pages 516 through 520 in Chapter VII of the 1994 Green Book. The primary intent of these revisions is to discourage the use of wider medians at intersections on urban and suburban arterials.

Medians

Medians are a desirable feature of arterial streets and should be provided where space permits. Medians and median barriers are discussed in Chapter IV. Where right-of-way is limited, it is frequently necessary to decide how best to allocate the available space between border areas, traffic lanes, and medians. On the less important arterials, the decision is often resolved in favor of no median at all. A median only 1.2 m wide is better than none; however, each additional ~~foot~~ **meter of median width** provides an added increment of safety and improved operation **between intersections. At intersections in urban and suburban areas, median widths should be limited, whenever possible, to those required to provide appropriate left-turn treatments for current and future traffic volumes.** At intersections where left turns are made, a left-turn lane is always desirable from a capacity and safety standpoint. The median width to accommodate left-turning movements should be at least 3.6 m. Desirably, the median should be at least 5.4 m wide for a 3.6-m median lane and a 1.8-m medial separator. At restricted locations, a 3.0-m lane with a 0.6-m medial separator may be used. **Other left-turn treatments, including double left-turn lanes and parallel or tapered offset left-turn lanes, may be needed at some intersections to serve current or future traffic volumes.**

Figure VII-5 shows various configurations for medians that may be used on urban arterials. The type of treatment usually depends on local practice and available right-of-way widths. The type selected should always be compatible with drainage and street hardware requirements.

Median openings on roadways provided with depressed or raised medians should be carefully considered when a divided arterial is planned. Openings should be provided only for street intersections or for major developed areas. Spacing between median openings must be adequate to allow for introduction of left-turn lanes and signal detection loops to operate without false calls.

Where intersections are widely spaced, e.g., 1.0 km or more, the median width may be varied by using a narrow width between intersections where necessary for economy and gradually widening on the approach to the intersection to accommodate the left-turn lane. This solution is hardly practical, however, and should never be used where intersections are closely spaced because the curved alinement of the lane lines results in excessive lane changes. It is far more desirable that the median be of uniform width.

A street with an odd number of lanes, perhaps three or five, may be used to advantage in providing a storage lane for left-turning vehicles. This lane is one form of utilizing a paved, flush median. Left-turn bays are marked in advance of the intersections. The length of lane between left-turn bays may be used for storage of vehicles making midblock left turns if this usage does not adversely affect traffic flow and safety on the arterial; otherwise, midblock left turns may be prohibited. Under some conditions it is better to permit midblock turns than to require that vehicles make U-turns at intersections or travel around a block to reach a destination. In some cases the center lane is designated for "Left-Turn Only" throughout, without specially marked bays at intersections. This type of operation works well where the speed on the arterial highway is relatively low (40 to 70 km/h) and there are no heavy concentrations of left-turn traffic. Figure VII-8 is an example of a continuous left-turn lane. Refer to Chapter IV, section "Medians" and Chapter IX, section

"Continuous Left-Turn Lanes" for further discussions of this type of median.

Where an arterial must pass through a developed area having numerous street and driveway intersections, and where it is impractical to limit left turns, the continuous left-turn median lane is often the only practical solution. Because all left turns are thus protected, the interference to through lanes is minimized. Successful operation of a continuous left-turn lane requires adequate lane marking.

A raised median with barrier-type curbing may be used on low and intermediate speed arterial streets. This type is desirable where it is necessary to prevent midblock turns. On streets serving low-speed traffic this type will prevent most cross-median accidents. Raised medians also provide a refuge for pedestrians and a good location for signs, signals, and other appurtenances. In snow-belt areas the curbed median provides positive delineation, whereas a flush median becomes indiscernible under the lightest of snowfall conditions. However, raised medians present disadvantages that should be considered in deciding the type to be employed.

On streets serving high-speed traffic the raised median does not prevent cross-median accidents unless a median barrier is provided. If accidentally struck, raised medians may cause the driver to lose control of the vehicle. They are difficult to see at night except when used in conjunction with a good system of fixed-source lighting or with proper delineation. They cast a shadow from oncoming headlights that not only makes the curb difficult to see, but also places most of the adjacent lane in shadow. Raised medians are of little use as a place of refuge for disabled vehicles unless they are very low with flat sloping curbs. In some cases the prevention of midblock turns causes operational problems because of heavy concentrations of left-turning traffic at the intersections.

The foregoing disadvantages of raised medians are largely eliminated when flush or low-profile mountable medians are used. However, flush-paved medians are also difficult to see at night when the pavement is wet. Visibility can be improved by use of a contrasting texture such as a chip seal coat and by proper delineation. Raised bars or blocks have proved to be ineffective as a median treatment and should not be used.

~~In suburban areas and elsewhere where a median width of 7.2 m or more can be provided, a flush or depressed landscaped median offers most of the advantages of a raised median with few of the unfavorable attributes.~~

Special consideration needs to be given to the width of medians when at-grade intersections are to be provided. **Research has shown that most types of undesirable driving behavior on the median roadway of divided highway intersections are associated with competition for space on the median roadway between vehicles traveling in the same direction through the median [reference this report]. Such problems are generally greater at urban and suburban intersections than at rural intersections, where volumes of turning and crossing traffic are lower. Types of undesirable driving behavior observed include side-by-side queuing, angle stopping, and encroaching on the through lanes of the divided highway. At suburban unsignalized intersections, the frequency of accidents and undesirable driving behavior were observed to increase as the median width increased. Thus, medians at suburban unsignalized intersections should not be wider than necessary. This trend is opposite to that observed at rural unsignalized intersections.**

The median at an urban or suburban unsignalized intersection should be wide enough to accommodate the left-turn treatment selected by the designer. As at rural intersections, the appropriate design vehicle for turning and crossing maneuvers, based on the vehicle mix for crossroad and U-turn traffic, should be considered in determining the median width. At urban and suburban unsignalized intersections, medians less than 25 ft wide can be used effectively and discourage drivers from stopping in the median, and discourage multiple vehicles traveling in the same direction from using the median at the same time. At locations with substantial crossing and turning volumes of larger vehicles, such as school buses or trucks, it may be appropriate to provide enough width to store such vehicles in the median without encroaching on the through lanes of the major road.

Urban and suburban unsignalized intersections with median widths from ~~9~~ **7.6** to 15 m **generally experience slightly higher accident rates than intersections with narrower medians but appear to** ~~should be carefully considered from an operational viewpoint. These widths do not always provide median storage space for longer vehicles crossing the median. Also, these widths may encourage the driver to attempt the crossings independently and leave the vehicle not fully protected from the through traffic. These widths, even with these problems,~~ operate quite well **[reference this report].** ~~and~~ **Such intersections** apparently are within the realm of normal operational expectations of the driver. **However, intersections with medians wider than 15 m have still more accidents, and intersections with medians wider than 18 m are difficult to signalize properly.**

~~Widths in a range of 15 to 24 m have developed accident problems in some areas as the drivers may tend to become confused about the intended operational characteristics of the multiple intersections encountered.~~

Experience shows that **at unsignalized intersections** drivers prefer medians that are obviously narrow or those that provide an adequate refuge area to allow independent roadway crossing operation.

At urban and suburban signalized intersections, research has found that accident experience increases as the median width increases [reference this report]. Therefore, median widths at urban and suburban signalized intersections should not be wider than necessary and should be determined primarily by the space required in the median for left-turn treatments. Median widths of more than 18 m are undesirable at intersections that are signalized or that may require signalization in the foreseeable future. The efficiency of signal operations decreases as the median width increases, because drivers require more time to traverse the median and special detectors may be needed to avoid trapping drivers in the median at the end of the green phase for traffic movements that pass through the median. Furthermore, if the median becomes so wide that separate signals are required on the two roadways of the divided highway, delays to motorists will increase substantially and careful attention must be given

to vehicle storage requirements on the median roadway between the two signals.

Uncurbed narrow medians often present problems with turning movements at intersections in that vehicles tend to run off the pavement edges. **An operational measure that appears promising is to provide guidance in the form of edge lines to accommodate the turning paths of passenger cars, while providing sufficient paved area beyond the edge lines to accommodate the turning path of an occasional large vehicle.**

A median barrier may be desirable on some arterial streets with relatively fast-moving traffic. It permits a positive separation of traffic and discourages indiscriminate pedestrian crossing. Where the median barrier is terminated at cross streets and other median openings, it should be turned down or flared to reduce the hazard. Reference is made to the *Roadside Design Guide* (*6*) for further discussion on treatment of the end of barriers. Additional information on median barriers and median treatments at intersection areas is contained in Chapters IV and IX, respectively. The information on medians and median barriers in Chapter IV is especially pertinent to urban arterials because they require the most varied application of these features.

GREEN BOOK CHAPTER IX (At-Grade Intersections)

The following revisions to the general discussion of median opening design on page 751 in Chapter IX of the 1994 Green Book are recommended. The primary intent of these changes is to incorporate the principle that the design of the median opening and median width is influenced by the area type (rural versus urban/suburban).

> The design of a median opening and median ends should be based on traffic volumes, **area type,** and type of turning vehicles, as discussed in Chapter II. Cross and turning traffic must operate in conjunction with the through traffic on the divided highway. This requirement makes it necessary to know the volume and composition of all movements occurring simultaneously during the design hours. The design of a median opening becomes a matter of considering what traffic is to be accommodated, choosing the design vehicle to use for layout controls for each cross and turning movement, investigating whether larger vehicles can turn without undue encroachment on adjacent lanes, ~~and finally~~ checking the intersection for capacity, **and evaluating the potential for operational problems related to undesirable driving behavior.** If the capacity is exceeded by the traffic load, the design must be expanded, possibly by widening or otherwise adjusting widths for certain movements. **The area type may influence the median width selected. Intersections in urban/suburban areas have been found to operate more safely with narrow medians, while unsignalized intersections in rural areas have been found to operate more safely with wider medians [reference this report].** Traffic control devices such as yield signs, stop signs, or traffic signals may be required to regulate the various movements effectively and improve the effectiveness of operations. **Wide medians may lead to inefficient traffic signal operation, however.**

The following revisions are recommended to a portion of the discussion on pages 752 through 754 in Chapter IX of the 1994 Green Book concerning control radii for minimum turning paths. The intent of these changes is to introduce a recommended approach for reducing the potential for erratic maneuvering by small vehicles where median openings with large paved areas are required.

> The customary at-grade intersection on a divided highway does not have a continuous physical edge of pavement delineating the left-turn path. Instead, the driver has guides at the beginning and at the end of the left-turn operation: (1) the centerline of an undivided crossroad or the median edge of a divided crossroad, and (2) the curved median end. For the central part of the turn the driver has the open central intersection area in which to maneuver. Under these circumstances for minimum design of the median end, the precision of compound curves does not appear necessary, and simple curves for the minimum assumed edge of the left turn have been found satisfactory. The larger the simple curve radius used, the better it will accommodate a given design vehicle, but the resulting layout for the larger curve radius will have a greater length of median opening and greater paved areas than one for a minimum radius. These areas may be sufficiently large to result in erratic maneuvering by small vehicles, which may interfere with other traffic. **To reduce the effective size of the intersection for most motorists, consideration should be given to providing an edge marking corresponding to the desired turning path for passengers cars, while providing sufficient paved area to accommodate the turning path of an occasional large vehicle.**

The following text presents recommended revisions to remove mention of a recommended 12-m minimum median opening length on page 757 in Chapter IX of the 1994 Green Book. During the research, intersections (particularly those with wide medians) were observed operating properly with median opening lengths as short as 9 m. Furthermore, the research found that the frequency of undesirable driving behavior increased as the median opening length increased.

> For any three- or four-leg intersection on a divided highway the length of median opening should be as great as the width of crossroad roadway pavement plus shoulders ~~and in no case less than 40 ft (or less than the crossroad pavement plus 8 ft)~~. Where the crossroad is a divided highway, the length of opening should be at least equal to the width of the crossroad roadways plus that of the median ~~plus 8 ft~~. The use of a ~~40-ft~~ minimum length of opening without regard to the width of median or the control radius should not be considered except at very minor crossroads. **Care should be taken not to make the median opening longer than necessary at rural unsignalized intersections.** The ~~40-ft~~ minimum length of opening ~~does not apply to openings~~ for U-turns~~, as~~ **is** discussed elsewhere.

In addition, consideration should be given to revising Figure IX-69 on page 776 of the 1994 Green Book to include the median width requirements for U-turns from a median left-turn lane to the inside lane, outside lane, and shoulder in the opposite direction of travel. It might also be useful to point out that Figure IX-69 can be used to determine the median width requirements

for U-turns at an intersection as well as at median openings intended solely for U-turns.

Changes are recommended on page 786 of the 1994 Green Book to remove the discussion of parallel offset left-turn lanes from the section entitled "Median End Treatment" and place it in a new section entitled "Offset Left-Turn Lanes." This section would also introduce the concept of a tapered offset left-turn lane. A figure would be added to the Green Book to illustrate parallel and tapered offset left-turn lanes. The text showing the recommended modifications is as follows:

> For medians wider than about 5.4 m as shown in Figure IX-74, it is usually preferable to **provide some offset between the left-turn lanes in the opposing directions of travel. Offset left-turn lanes of this type are discussed in the next section.** ~~align the left-turn lane in a manner that will reduce the width of the divider to 1.8 to 2.4 m immediately in advance of the intersection, rather than to aline it exactly parallel with and adjacent to the through lane. This alinement will place the vehicle waiting to make the turn as far to the left as practical and thus provide appropriate visibility of opposing through traffic. The advantages of aligning the left-turn lanes are: (1) better visibility of opposing through traffic; (2) decreased possibility of conflict between opposing left-turn movements within the intersection; and (3) more left-turn vehicles served in a given period of time, particularly at a signalized intersection.~~
>
> ~~Any excess area within the median to the right of the left-turn lane should be paved, preferably with contrasting pavement, or provided with painted channelization and maintained flush with the roadway surface as described in the preceding section.~~

For curbed dividers 1.2 m or more in width at the narrowed end, the curb nose can be offset from the opposing through traffic lane 0.5 m or more, with gradual taper beyond to make it less vulnerable to contact by through traffic, as shown in Figure IX-73B. The shape of the nose for curbed dividers 1.2 m wide usually is semicircular but, for wider width, the ends are normally shaped to a bullet nose pattern to conform better with the paths of turning vehicles.

Offset Left-Turn Lanes

For medians wider than about 5.4 m it is desirable to align the left-turn lane so that it will reduce the width of the divider to 1.8 to 2.4 m immediately before the intersection, rather than to align it exactly parallel with and adjacent to the through lane. This alignment will place the vehicle waiting to make the turn as far to the left as practical, maximizing the offset between the opposing left-turn lanes, and thus providing improved visibility of opposing through traffic. The advantages of aligning the left-turn lanes are (1) better visibility of opposing through traffic; (2) decreased possibility of conflict between opposing left-turn movements within the intersection; and (3) more left-turn vehicles served in a given period of time, particularly at a signalized intersection. Parallel offset left-turn lanes may be used at both signalized and unsignalized intersections. This left-turn lane configuration is referred to as a parallel offset left-turn lane and is illustrated in Figure IX-74A.

An offset between opposing left-turn vehicles can also be achieved with a left-turn lane that diverges from the through lanes and crosses the median at a slight angle. Figure IX-74B illustrates a tapered offset left-turn lane of this type. Tapered offset left-turn lanes provide the same advantages as parallel offset left-turn lanes in reducing sight distance obstructions and potential conflicts between opposing left-turn vehicles and in increasing the efficiency of signal operations. Tapered offset left-turn lanes are normally constructed with a 1.2-m nose between the left-turn lane and the opposing through lanes. Tapered offset left-turn lanes have been used primarily at signalized intersections.

Parallel and tapered offset left-turn lanes should be separated from the adjacent through travel lanes by painted or raised channelization.

Two figures would accompany the preceding material in the Green Book. These figures, which would be designated in the Green Book as Figures IX-74A and IX-74B, are presented here as Figures G-1 and G-2.

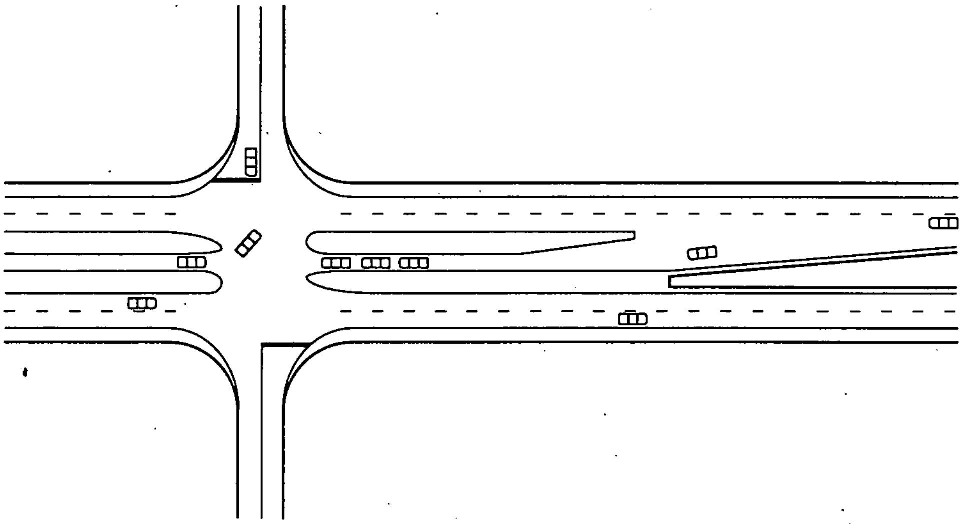


Figure G-1. Parallel offset left-turn lane (proposed Green Book Figure IX-74A).

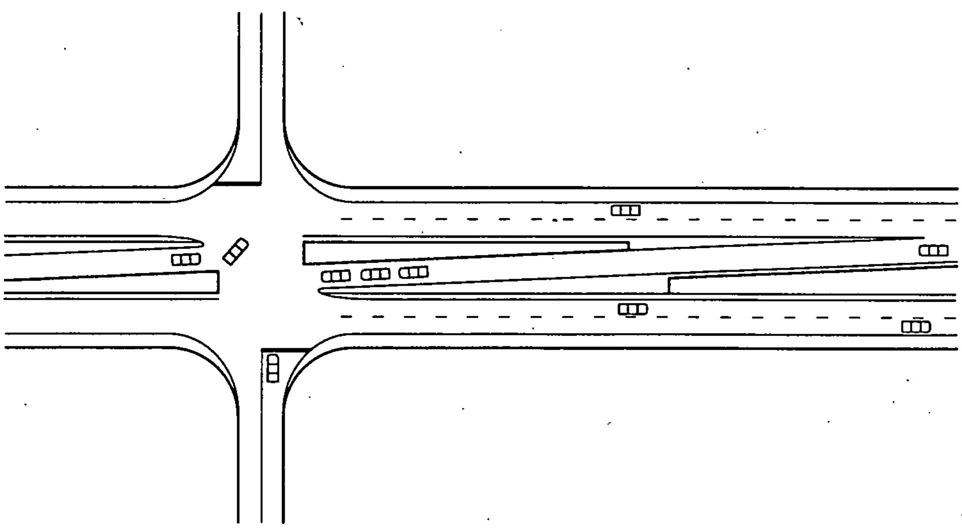


Figure G-2. Tapered offset left-turn lane (proposed Green Book Figure IX-74B).

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

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

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

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

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

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED