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The overall objective of Study 1107 is to discover an alternative means of increasing the supply of high-quality traffic service in urban areas. Urban freeways have, for a variety of reasons, become overloaded and difficult to augment. A plausible alternative is to improve the quality and scope of the urban arterial street system so that these streets can supplement the services furnished by the freeway system. For the purposes of this study, these improved urban arterial streets are designated as strategic arterial streets (SAS). The concept of the SAS addressed in this study is that of streets providing a higher level of traffic service and productivity than existing urban arterial streets but less than that afforded by freeways. Systems analysis shows that if arterial streets operate at higher speeds and have sufficient capacity, they can divert significant amounts of traffic from freeways. The problem is: what are the factors which affect the speed and capacity of arterial streets? The guidelines presented in this report (1107-4) address the principal factors which affect the quality of service and productivity of these streets. The principal factors are geometric design, control of access, and operational controls. Geometric design features discussed are cross sections, auxiliary lanes, median barriers, intersection layouts, access driveways, and grade separations. The consequences and means of control of access are addressed. The effect and frequency of traffic-signalized intersections on travel speed are addressed. Additional issues addressed are transit operations, pedestrian activity, implementation, and future directions.

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DESIGN GUIDELINES AND OTHER CONSIDERATIONS FOR STRATEGIC ARTERIAL STREETS

by

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Research Report Number 1107-4

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The Role of the Arterial Street System in Urban Mobility

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PREFACE

This report, entitled "Design Guidelines and Other Considerations for Strategic Arterial Streets" (1107-4) is one of *five* reports prepared under Research Study 2/3-8-88/0-1107, "The Role of the Arterial Street System in Urban Mobility." Study 1107 was a cooperative study conducted jointly by the Texas Transportation Institute (TTI) and the Center for Transportation Research (CTR).

The genesis of this report is to discover means of improving traffic mobility in larger cities. These cities may have become overly dependent upon freeways for accommodating intermediate-length vehicular trips (3 to 10 miles), and, as a result, many freeway systems are becoming overburdened. For various reasons, the supply of freeway facilities has not kept up with trip demands. A plausible alternative to increasing the supply of freeway facilities is to improve the scope and quality of urban arterial street systems.

This report primarily addresses the geometric design factors that are necessary for an urban arterial street to provide the quality of service that is characteristic of a *strategic arterial street* (SAS). Within the context of this study, a SAS is defined as a street which provides higher-quality traffic service than an ordinary arterial street but a lower quality than that provided by a freeway. The level of service prescribed for a SAS *in this study* is, however, considered sufficient for it to attract a significant amount of traffic from the freeway system and also provide a higher level of traffic service for urban areas which do not have convenient access to the existing freeway system.

This study also looks at some other considerations affecting the planning, design, operation, and implementation of a SAS System. Among these are access control, pedestrians, and public transit. Also included is a brief description of urban arterial street improvements in California and in New Jersey, along with a discussion of political and jurisdictional issues which might affect the implementation of a SAS System.

During the course of this study, field trips were made to New Jersey and California to observe in situ urban conditions and urban arterial street operations which were thought to be relevant to this study and to discuss the planning and design of urban arterial streets with appropriate officials. Consequently, our appreciation for assistance is extended to Mr. Edwin W. Dayton, Director, Division of Roadway Design, New Jersey DOT and his associates; Mr. Donald W. Dey, Principal Traffic Engineer, City of Anaheim, California; Mr. S. E. (Ed) Rowe, General Manager, Department of Transportation, City of Los Angeles, California; and Mr. Arya Rohani, Special Projects Manager, Orange County Transportation Commission, Santa Ana, California.

LIST OF REPORTS

(1) Research Report 1107-1: "An Enhanced Role for the Arterial Street System in Texas Cities," by Dennis L. Christiansen and W. V. Ward. Published by TTI.
(2) Research Report 1107-2: "An Analysis of the Potential for Traffic Diversion to a Strategic Arterials System," by James A. Mullins III and Jim D. Benson. Published by TTI.
(3) Research Report 1107-3: "Mobility Impacts of Improving an Arterial Street," by Kay Fitzpatrick, Bruce Rymer, and Thomas Urbanik II. Published by TTI.
(4) Research Report 1107-4: "Design Guidelines and Other Considerations for Strategic Arterial Streets," by Theunis J. Kruger, Clyde E. Lee, Randy B. Machemehl, and W. V. Ward. Published by CTR.
(5) Research Report 1107-5F: "Cost-Effectiveness and Guidelines for Strategic Arterial Street System," by Thomas Urbanik II, W. V. Ward, Kay Fitzpatrick, and Theunis J. Kruger. Published by TTI.

ABSTRACT

The overall objective of Study 1107 is to discover an alternative means of increasing the supply of high-quality traffic service in urban areas. Urban freeways have, for a variety of reasons, become overloaded and difficult to augment. A plausible alternative is to improve the quality and scope of the urban arterial street system so that these streets can supplement the services furnished by the freeway system. For the purposes of this study, these improved urban arterial streets are designated as *strategic arterial streets* (SAS). The concept of the SAS addressed in this study is that of streets providing a higher level of traffic service and productivity than existing urban arterial streets but less than that afforded by freeways. Systems analysis shows that if arterial streets operate at higher speeds and have sufficient capacity, they can divert significant amounts of traffic from freeways. The problem is: what are the factors which affect the speed and capacity of arterial streets? The guidelines presented in this report (1107-4) address the principal factors which affect the quality of service and productivity of these streets. The principal factors are geometric design, control of access, and operational controls. Geometric design features discussed are cross sections, auxiliary lanes, median barriers, intersection layouts, access driveways, and grade separations. The consequences and means of control of access are addressed. The effect and frequency of traffic-signalized intersections on travel speed are addressed. Additional issues addressed are transit operations, pedestrian activity, implementation, and future directions.

SUMMARY

Declining mobility is a serious problem in most large urban areas. As these areas have grown in population and area, the demand for traffic services provided by the highway and street facilities has also increased. In particular, the demand for *high-quality* traffic services, as provided by freeways, has increased much faster than the ability to expand the freeway system. It is generally agreed that many freeways and some freeway networks serving some of the larger urban areas are carrying a disproportionate share of the total traffic load.

The overall objective of this study is to discover an alternative to increasing the capacity of urban freeways which, for a variety of reasons, have become overloaded and difficult to augment. One plausible alternative is to improve urban arterial streets so that they furnish a more competitive quality of traffic service. This report presents and discusses guidelines for the design of a class of improved urban arterial streets which are called herein *strategic arterial streets*. The guidelines examine and discuss the various aspects of arterial street design and operations and identify the combination of factors and conditions that are requisite if an urban street is to deliver the desired high quality of traffic service.

Computer analysis of a network of interconnected highways and streets of various functional classifications shows that *improved* arterial streets can divert a significant amount of traffic from the freeway system and the other arterial streets *provided* the arterials operate at *higher* speed than the *other arterial streets* and carry significant volumes of traffic. These guidelines suggest design and operational parameters which, if implemented, should provide the quality of service and traffic capacity to yield a facility which should accommodate the demand for medium-length trips of 3 to 10 miles. The functional classification of highways and streets assumes that the higher classification facilities (i.e., freeways and arterials) should accommodate the longer trips while the lower classifications (i.e., collector and local streets) should accommodate the shorter trips.

The concept of *strategic arterial streets* is to have arterials which provide higher capacity and travel speed than are normally found on arterial streets. Such streets can offer an attractive alternate travel path for a significant number of trips and furnish high-quality traffic service to new-growth areas. The Texas State Department of Highways and Public Transportation is interested in exploring the effect of strategic arterials on the state highway system as well as on the highway and street systems owned by others.

Although freeways are characteristically capable of providing higher-quality traffic service than are thoroughfares, there are several apparent reasons why improving arterial streets is considered expedient and attractive:

(1) significantly lower construction costs per lane-mile;
(2) the opportunity to place in operation short, usable increments of roadway which can begin generating user-benefits sooner—freeways, by design, serve longer trips and need to be constructed in longer elements in order to be effective;
(3) the adaptability of a thoroughfare system to changes in land use and population; and
(4) the accommodation of enhanced express and cross-town bus transit service.

More specifically, this report focuses on

(1) describing the role of strategic arterials within the hierarchy of existing road classes;
(2) defining desired operational characteristics of strategic arterials;
(3) developing guidelines for providing features which should be present on strategic arterials in order to produce the desired traffic service;
(4) establishing a basis from which to derive appropriate design standards for strategic arterials;
(5) outlining required standards of geometric design;
(6) identifying the most important implementation issues;
(7) providing guidelines to direct the analysis of strategic arterials and establish a hierarchy, or phasing, for improvement implementation; and
(8) addressing the political issues related to planning, building, and operating a strategic arterial street system.

IMPLEMENTATION STATEMENT

This report is intended to present in a single document the factors that appear to be the most significant in the planning, design, implementation, and operation of improved urban arterial streets. This report focuses on those design and operation parameters applicable to a suggested new-functional-class of urban roadway facility, designated in this report as a *strategic arterial street*. The basic principles and parameters of design suggested in this report, as applicable for strategic arterials, differ only in degree from those applicable to roads and streets of different functional classification. This report should be immediately useful to anyone interested in the concept of improving and extending the range of urban arterial streets as an alternative strategy to enhance urban mobility.

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CHAPTER 1. INTRODUCTION

OBJECTIVE

The overall objective of the study reported herein is to discover an alternative to increasing the capacity of urban freeways which, for a variety of reasons, have become overloaded and difficult to augment. One plausible alternative is to improve urban arterial streets in order to furnish a more competitive quality of traffic service. This report presents and discusses guidelines for the design of a class of improved urban arterial streets which are herein called *strategic arterial streets*. The guidelines examine and discuss various aspects of arterial street design and operations, and identify the combination of factors and conditions necessary for an urban street to deliver the high quality of traffic service desired.

BACKGROUND

Declining mobility is a serious problem in most large urban areas. As these areas have grown in population and size, the demand for traffic services provided by the highway and street facilities has also increased. In particular, the demand for *high-quality* traffic services, as provided by freeways, has increased much faster than the ability to expand the freeway system. It is generally agreed that many freeways and some freeway networks serving some of the larger urban areas are carrying a disproportionate share of the total traffic load. In the more populated counties of Texas, the freeway facilities, which may constitute only 2 to 3 percent of the county's total highway and street mileage, carry over 40 percent of the vehicle-miles traveled within these counties.

Increasing the supply of freeway facilities is becoming a less feasible option because of environmental, political, and financial constraints, and there are other factors inhibiting the process of planning and constructing freeway improvements. The duration and uncertainty of the process often seem to exceed the horizon of ordinary human patience and expectations. It is difficult to generate the commitment necessary to effect a program for adding substantial freeway capacity if the realization of that program may require 15 years for negotiating, planning, designing, and constructing the facility. This is particularly true if a substantial amount of improved rights-of-way is required. The success of this lengthy process may be further jeopardized by the ever- present risk that the program may fail during planning, because of political, economic, or legal difficulties.

Furthermore, adding capacity to an existing freeway in an urban area is exceptionally expensive. Added freeway capacity is most likely needed where traffic is most intense, and property values along freeways tend to escalate in proportion to the amount of freeway traffic. The high cost of capacity improvements is further aggravated by the need to accommodate existing traffic within the construction zone and to maintain access to abutting property during construction. Nevertheless, freeways carry more traffic per lane more quickly and more safely than other types of highways, and urban freeway capacity improvements are usually cost-effective in spite of their extraordinarily high cost. Regardless of the effectiveness of freeways, urban freeway systems are not being expanded sufficiently to keep up with the demand for high-quality traffic service, and other solutions to this problem must be considered.

The option to increase the investment in (and encourage more use of) public transit has not, in practice, yielded the desired results. The predominant American lifestyle today in large urban areas is represented by suburban residency coupled with commute trips to a widely dispersed and unfocused collection of high-activity centers for employment, shopping, entertainment, and services. Such a life-style is unfavorable to the propagation of and dependence on public transportation. Consequently, it is not likely that increased investment in public transit will have much effect on highway and street traffic congestion in the immediate future.

Recently, attention has been directed toward finding ways of enhancing the urban arterial street system in order to increase the supply of higher-quality traffic service. There is evidence that many large urban areas have become overly dependent upon the freeway system and have been negligent in making improvements to arterial streets to supplement the freeway system. It is likely that at least some of the congestion on freeways can be moderated by providing attractive alternate facilities to intercept short trips that would otherwise use a freeway. Such trips may often originate in new-growth areas, which do not now have convenient access to the existing freeway system and may never have the same degree of convenient access as the older urban areas.

The concept of *strategic arterial streets* involves arterials which provide higher capacity and travel speed than normally found on arterial streets. Such streets can offer an attractive alternate travel path for a significant number of trips and furnish high-quality traffic service to new-growth areas. The Texas State Department of Highways and Public Transportation (SDHPT) is interested in exploring the effect of strategic arterials on the state highway system as well as on the highway and street systems owned by others.

Although freeways are characteristically capable of providing higher-quality traffic service than thoroughfares, there are several apparent reasons why the improvement of arterial streets is considered expedient and attractive:

(1) the significantly lower construction costs per lane-mile;
(2) the opportunity to place in operation short, usable increments of roadway which can begin generating user benefits sooner (freeways, by design, serve longer trips and need to be constructed in longer elements in order to be effective);
(3) the adaptability of a thoroughfare system to changes in land use and population; and
(4) the accommodation of improved express and cross-town bus transit service.

Another alternative to the strategic arterial and freeway alternative is to expand the existing arterial street system. Such an option is a do-nothing alternative, since it represents a continuation of traditional planning and does not address the increasing demand for higher-quality traffic services. Traditional planning policies recognize the need for arterial streets and are generally able to cope with the need for lower-quality traffic services by expanding the existing arterial street system. The conventional arterial street system does not, however, furnish enough service to be a surrogate for a freeway system or provide an attractive alternative which will divert a significant number of trips from the existing freeway system. Design guidelines for strategic arterials described herein are submitted with the notion of demonstrating standards for facilities that can provide traffic services of higher quality than those attainable from traditional arterials but, unavoidably, of quality lower than that attainable from freeways. To be considered an attractive alternative, strategic arterials must yield users' benefits—a derivative of the design—which outweigh the increase in installation costs. Otherwise, the do-nothing alternative will probably prevail.

SCOPE OF STUDY

This study addresses a class of improved urban arterial streets whose intended function is to serve relatively high volumes of traffic at relatively high speeds and to attract moderate-length trips (as opposed to longer freeway trips) from freeways and other urban arterial streets. For purposes of this study, these streets are called Strategic Arterial Streets (SAS). If they are addressed severally or as a network, they are called a Strategic Arterial Street System (SASS). This name has been coined for this study, upon the advice and consent of the SDHPT, in order to distinguish facilities *addressed by this study* from those arterial streets included within the SDHPT's Principal Arterial Street System (PASS). The word *strategic* as used in this study conforms to one of Webster's definitions: "of great importance within an integrated whole or to a planned effect."

The American Association of State Highway and Transportation Officials (AASHTO), in its 1984 edition of *A Policy on Geometric Design of Highways and Streets* (Ref 18), classifies highways in urban areas by *functional* systems as a hierarchy, from those providing the highest quality of traffic service to those providing the least quality: principal arterials, minor arterials, collector roads, and local roads. Components of the principal arterial system are further substratified as (1) interstates, (2) other freeways and expressways, and (3) *other principal arterials (with partial or no control of access).* The arterial street system envisioned in this study would for the most part be considered as subset (3).

TERMINOLOGY

The term "superstreet" is commonly used to describe higher-quality street improvements which provide not only increased traffic capacity but increased travel speeds, reliability of operations, and range of service. Whether a street is truly "super" is in the eye of the beholder, and the term is intended to convey the idea of a street delivering traffic service of a quality significantly higher than the prevailing community standards but less than that expected from a freeway of adequate capacity. The term "superstreet," which succinctly promises much and evokes a vision of some higher form of urban street travel, may have been first coined by the Orange County, California, Transportation Commission in the mid-1970's in order to call attention to and promote improvements to some principal arterial thoroughfares. More specifically, the Orange County concept is to upgrade selected arterial streets by widening intersections and restriping, improving traffic signal coordination, closing median openings, consolidating driveways, controlling access, installing grade separations at critical intersections, and adding lanes along some segments.

Other terms that have been used are "principal arterials," "high-flow arterials," "continuous-flow boulevards," "regional arterials," and "regional thoroughfares." In any case, the idea is to designate and set apart this particular type of street for purposes of identification and discussion, although physically and functionally these alternate designations are intended to convey the idea of a road facility conforming to subset (3) in the above paragraph: other principal arterials *(with partial or no control of access).*

The SDHPT has adopted the term Principal Arterial Street System (PASS) in describing one of its funding programs designed to improve traffic operations along arterial streets in urban areas. As mentioned previously, the term Strategic Arterial Street System (SASS) has been adopted for purposes of this study to distinguish the facilities and network addressed by this study from other similar facilities on the SDHPT's Principal Arterial Street System and any other designated arterial network.

GUIDELINES

The following guidelines are intended to assist those interested in benefiting urban mobility by upgrading and improving the operations of arterial street facilities. In planning systems that incorporate strategic arterials, the first step is to specify the *desired operating characteristics* of the strategic arterials. The next step is to determine the resulting travel demand for an arterial system having the specified characteristics. For system simulation purposes, it is easy to specify any desired quality of speed or capacity for a given functional class of road. The simulated traffic demand will then reflect the specified operating qualities. The challenge in practice is to construct and operate arterial streets that will deliver what is desired. *These guidelines address the desired operating characteristics of an improved arterial street and identify and discuss the factors necessary to produce these characteristics*. The guidelines also address some of the political issues that may affect the planning, construction, financing, and operation of improved arterial streets.

Specifically, this report focuses on

(1) describing the role of strategic arterials within the hierarchy of existing road classes;
(2) defining desired operational characteristics of strategic arterials;
(3) developing guidelines for providing features which should be present on strategic arterials in order to produce the desired traffic service;
(4) establishing a basis from which to derive appropriate design standards for strategic arterials;
(5) outlining required standards of geometric design;
(6) identifying the most important implementation issues;
(7) providing guidelines to direct the analysis of strategic arterials and establish a hierarchy, or phasing, for improvement implementation; and
(8) addressing the political issues related to planning, building, and operating a strategic arterial street system.

CHAPTER 2. ROADWAY CLASSIFICATION AND ITS USE IN THE DERIVATION OF PLANNING AND DESIGN CRITERIA

INTRODUCTION

In developing design guidelines for strategic arterials, it is useful to consider the function of strategic arterials with respect to that of other highway and street facilities. Functional classification serves as a standard of reference for discussion purposes and provides a means to coordinate and compare appropriate design guidelines.

There are existing guidelines which correlate highway and street functions and suggest appropriate design standards for each functional class of highway. The American Association of State Highway and Transportation Officials (AASHTO) publication entitled *A Policy on Geometric Design of Highways and Streets* (Ref 18) is the most commonly used reference for such design standards. This policy presents a compendium of practice as well as standards suitable for use in designing and analyzing highways and streets in the various functional classes.

CLASSIFICATION SCHEMES

All highways and streets, regardless of owner, are classified for operational and planning purposes. Different planning agencies may classify the same highways and streets differently, or at least assign different designations to highways and streets having the same function. There are several schemes used to classify highways. Most highways and streets are classified under two or more schemes. Among these are the following.

(1) Classification according to physical design and access control. This classification is usually related to appearance. The term *parkway,* for example, is often used to convey the image of a highway or street on which trucks may be prohibited; which has a grassy or landscaped median, verge, and some control of access; and along which adjacent commercial activities may be restricted.

(2) Classification by route designation and symbol. This scheme is useful for designating traffic routing and operations. Examples of this in Texas are farm roads, ranch roads, park roads, business routes, truck routes, loops, bypasses, belts, and scenic routes.

(3) Administrative classification related to funding and functional programs. This type of classification is sometimes used by various levels of government for allocating funding for different purposes. For example, the Federal Government has designated specific funding for the Interstate program, primary program, secondary-roads program, bridge-replacement program, demonstration programs, etc.

(4) Functional classification for planning purposes. Here, highways are grouped into types by the character of service which they provide. This is the most prominent and most often used highway classification scheme. This scheme of classification is described in Reference 18 and is discussed further in the following section.

FUNCTIONAL CLASSIFICATION

AASHTO's *A Policy on Geometric Design of Highways and Streets* (Ref 18) provides discussion of and guidelines concerning functional classification and its application to design procedures.

Criteria

The two major considerations in applying functional classification are the functions of mobility and access. The basic rationale is that higher-order facilities will serve the mobility requirements of users of the system, while the lower-order roads and streets will primarily serve access needs. At the lowest end of the scale are the road and street types associated with the terminations of trips.

As the primary subject of this study is urban streets (and specifically a higher order of urban streets), a short summary of the specific functions of each class of urban street is offered.

The four functional classes of urban streets are (Refs 18 and 47):

(1) Principal arterials, which
  - serve the major activity centers;
  - carry high volumes of traffic;
  - serve the longer trips;
  - serve the highest proportion of vehicle-miles traveled in an urban area; and
  - carry most trips entering or leaving the area, as well as through-movements which bypass central areas.

  To preserve the identification of controlled-access facilities, specifically interstate freeways, principal arterials are stratified into
  - Interstate,
  - Other Freeways and Expressways, and
  - "Other" Principal Arterials.

  Other nomenclature is sometimes used to refer to urban street classes. Primary Arterial and Secondary Arterial are terms used instead of Other Principal Arterial and Minor Arterial, respectively.

(2) Minor Arterials, which interconnect with and augment the principal arterial system.

(3) Collectors, which provide for circulation within residential, commercial, and industrial areas while also serving direct land access.

(4) Local Streets, which primarily provide direct land access, and on which through-traffic is generally discouraged.

Table 2.1 Functional roadway classification and general planning guidelines

	Freeway and Expressway	Strategic Arterial	Primary Arterial	Secondary Arterial	Collector	Local
Function	Traffic movement	▨	Primary: Longer-distance intercommunity and intrametro area high-capacity traffic movement Secondary: Land access	Primary: Moderate distance intercommunity and intrametro area traffic movement Secondary: Land access	Primary: Collect/distribute traffic between local streets and arterial system Secondary: Land access Tertiary: Inter-neighborhood traffic movement	Land access
Typical percent of surface street system milege	N.A.	▨	5 to 10%	10 to 20%	5 to 10%	60 to 80%
Continuity	Continuous	▨	Continuous	Continuous	Not necessarily continuous; should not extend across arterials	None
Approximate spacing (miles)	4	▨	1 to 2	1/2 to 1	1/2 or less	As needed
Typical portion of surface street system vehicle-miles carried	N.A.	▨	40 to 65%	25 to 40%	5 to 10%	10 to 30%
Direct land access	None	▨	Limited: major generators only	Restricted: some movements may be prohibited; number and spacing of driveways controlled	Safety controls; limited regulations	Safety controls only
Minimum roadway intersection spacing	1 mile	▨	1/4 mile	1/8 mile	300 feet	300 feet
Speed limit (mph)	45 to 55	▨	35 to 45 in fully developed areas	30 to 35	25 to 35	20 to 30
Parking	Prohibited	▨	Prohibited	Generally prohibited	Limited	Permitted

Source: Reference 47

Application of Functional Classification

AASHTO (Ref 18) provides a clear case to show how functional classification relates to appropriate design standards and, at least conceptually, to levels of service. Arterials, as they serve longer trip lengths and the majority of the vehicle-miles traveled in a system, are expected to provide the highest degree of mobility and should, therefore, provide for high operating speeds and high levels of service. On the other end of the scale, local streets serve short trips and—as property access is their main function—have little need to provide high mobility or to have high operating speeds. Lower design speed and lower levels of service are therefore appropriate for local streets. This fundamental concept is used to provide consistent guidelines and design standards for various road classes.

Several references, such as the Institute of Transportation Engineers' (ITE) *Recommended Practice for the Planning of Urban Arterial and Freeway Systems* (Ref 47) and Stover and Kopeke (Ref 48), provide for the consideration of the functional classes within the context of a network by suggesting guidelines for spacing and continuity of the different road classes. Reference 47 also includes relevant elements of the AASHTO policy. These are summarized in Table 2.1, and the suggested position of strategic arterials is shown (shaded).

Although the 1984 AASHTO policy relates level of service to the various road classes, none of the above-mentioned references provides a clear indication of operational standards for the various classes. It is recognized, however, that

(1) the access function and the mobility function are, more often than not, in conflict;
(2) the on-street-parking and the mobility function are in conflict; and
(3) the general design characteristics of the road are related to a suitable speed limit and to the operating speeds, which can be expected to prevail.

Access and mobility inherently conflict. The Colorado Department of Highways launched an access-control demonstration project, which primarily investigated the effects of access control on mobility resulting from implementation of the state's access laws and the State of Colorado Access Code (Refs 49, 50, and 51). The Colorado Access Code, which is probably the first published attempt to set out regulations controlling access, illustrates how design standards and criteria for access control and signal control can be derived from the application of functional classification. The code and the demonstration project are discussed further in Chapter 4 of this report.

THE STRATEGIC ARTERIAL WITHIN THE CONTEXT OF FUNCTIONAL CLASSIFICATION

Proposed Strategic Arterial Streets (SAS), as described herein, are clearly in the functional class of Urban Principal Arterials; therefore, planning and design guidelines should concentrate on the higher end of the range of existing design and operational criteria for non-freeway and non-expressway principal arterials and strongly focus on design and traffic-control features which can be attained in practice. Route continuity and consistency in design standards should also receive special attention. The primary focus of this document is on guidelines for geometric design, intersection treatments (including signal-controlled and grade-separated intersections), and management of property access.

Within the conventional functional classification scheme, it is appropriate to describe a strategic arterial as an urban street designed, controlled, and managed to function as an urban principal arterial with design characteristics tending toward the higher end of those applicable to non-freeway urban principal arterials. Design guidelines recommended for strategic arterials include

- providing safe traffic operations at a selected design speed of 45 to 50 mph;
- accommodating moderate-to-high traffic volumes (on the order of 800 to 1,000 vehicles/hour/lane, with total volumes of 2,000 to 3,000 vehicles per hour per direction); and
- serving a major portion of the medium-length trips in an urban area or corridor (typical trip lengths of 5 to 10 miles, on facilities continuous for 3 to 8 or more miles) at moderate travel speeds (30 to 45 mph).

CHAPTER 3. CONSIDERATIONS IN DEVELOPING GUIDELINES FOR STRATEGIC ARTERIALS

GENERAL

As a matter of function, strategic arterials are expected to provide mobility at levels beyond those normally found on arterial streets. They may also provide some level of land access and can even accommodate a number of other traffic-related functions such as parking, loading, and pedestrian activity. The effects of inherently higher traffic volumes and speeds can potentially increase the hazard to strategic arterial users and to the adjacent environment; therefore, safety must always be considered as a cardinal element in developing a strategic arterial and in selecting appropriate design parameters and improvement strategies. Another element that can play a role in the provision of safety and high levels of traffic operations is positive guidance. Application of the basic principles of positive guidance tends to satisfy driver expectancy through proper choice of design elements and traffic control techniques.

Also to be considered are the political and social influences which affect the planning and development of all road and street facilities. Many decisions and choices of alternatives that have heretofore often been considered strictly a matter of choice for an engineer and his conscience may now have to pass a political test and be subjected to public scrutiny before they can be ordained. It is a paradox of modern-day politics that the infrastructure in urban areas, which is suffering the worst congestion and obsolescence, will often be the most difficult to restore and improve. Planners and designers must, therefore, be aware of this situation and adapt their plans and design parameters accordingly. Frequently there are tradeoffs that a designer can make in order to satisfy functional requirements as well as political and social influences. Examples of this are reduced design speed, modified grade lines, provision of pedestrian grade-separations, use of barrier fencing, and landscaping.

The basic goal in establishing design guidelines for strategic arterials is to incorporate some of the desirable functional characteristics normally associated with freeways while also considering the effectiveness of certain operational features associated with high-quality urban streets. Associated with the selection of geometric design features for strategic arterials is the notion that there is a noticeable difference in the philosophy of traffic management on freeways and on arterial streets. Freeways, which have inherent operational advantages resulting primarily from the fact that there are no at-grade intersections and relatively infrequent points of ingress and egress, generally do not require a great deal of traffic management. The freeway management techniques that are used usually deal with traffic-incident management and control of traffic input. These techniques, which are most effective during peak traffic periods, tend to smooth traffic flow and enhance reliability of service. They are cost-effective even though they do not greatly affect the quality of service during off-peak traffic periods. Strategic arterial streets, on the other hand, will not have as many built-in features as freeways to improve the quality of traffic service; therefore, traffic management has greater potential for effecting a relative improvement in traffic service on these facilities than on freeways.

As will be discussed further, the quality of operations and the productivity of strategic arterials are closely tied to the allocation of green-time at signalized intersections. This allocation must be carefully managed. An adequate proportion of the available green-time at all signalized intersections must be assigned to the strategic arterial if acceptable traffic operations are to be established and maintained.

It is recommended that average travel speed be used as the primary measure of effectiveness to describe the quality of traffic operations on strategic arterials. Special emphasis must be placed on providing a consistent speed throughout the length of the facility.

PRODUCTIVITY

The productivity of an arterial street is defined as a function of both the speed and volume of traffic flow. Productivity may also be considered as a measure of efficiency and quality of service. For example, Street A, assumed to accommodate 10,000 vehicles per day per lane at an average daily speed of *40 miles per hour*, would be considered more efficient than Street B, assumed to accommodate the same amount of traffic at a *lesser* average speed.

Considering the owner's (public agency having responsibility) and planner's economic interests, productivity is closely related to the *volume* of traffic flow for a given facility. The more traffic a facility will attract and accommodate, the more cost-effective it is likely to be. Considering *only* the user's interests, quality of service is proportional to the *average* travel speed afforded by a street facility. For planning and comparison purposes, it is suggested that the *average* daily weekday speed be applied. This is defined as the speed weighted for the traffic volume and travel speed for each hour of each day. Consequently, average speed is influenced by the travel patterns and peak-hour characteristics for a particular route. The *hierarchy* of the functional classification of the various types of roads and streets (see Chapter 2) is also related to the productivity.

Figure 3.1 shows the relationship of productivity among several different types of highway and street facilities. These curves were prepared for CTR Research Report 428-1F, "Conceptual Strategic Arterial Street System for Harris County." The curves show the variation in productivity for a variety of six-lane road and street facilities. Productivity is primarily influenced by the presence of at-grade crossing traffic and access control. The bottom curve in Figure 3.1, shown as a dashed line, exemplifies the productivity of an undivided city street. This type of street may be characterized as having (1) frequent at-grade intersections, some of which are signalized and some are not; (2) no provisions for turning lanes at the intersections; and (3) little or no control of street parking and access. The top curve, also a dashed line, represents freeway productivity. The heavy solid lines in the middle of Figure 3.1 represent the range of productivity of a conceptual strategic arterial street. The productivity of the strategic arterial is much affected by the frequency of occurrence (spacing) of signalized at-grade intersections, as shown in Figure 3.1. Productivity is higher if intersections occur less frequently.

Productivity may be demonstrated by comparing values represented by the curves in Figure 3.1. For example, at an average daily traffic (ADT) of 50,000, the city street would permit an average daily speed of about 25 mph, while the strategic arterials would permit a speed range of 35 to 45 mph. The peak hour speeds would, of course, be much less. At this volume of traffic, the freeway would operate at a speed of close to 60 mph.

The productivity curves for the strategic arterials were synthesized by using the TEXAS Model for Intersection Traffic, a computer-simulation model. In evaluating the effect of at-grade intersections on the traffic operations of arterial streets, it was assumed that the arterial traffic would be allocated 70 percent of the signal cycle length at any intervening signalized at-grade intersection. Consequently, productivity is enhanced by allocating more green-time to the arterial traffic and vice versa. Figure 3.1 is very generalized, and there are additional factors which can affect the productivity of each of the classes of roads and streets displayed.

Additional factors which affect quality of service are safety, reliability of traffic operations, and a user-friendly environment. These factors are much more difficult to forecast and to quantify than average traffic speed and volume and are more subjective in assessment than average speed and traffic volumes. These factors are generally taken into consideration when establishing standards and guidelines for the design of street facilities. The effect of the these factors on quality of service is usually appraised in accordance with the discretion and judgment of the planners and design engineers.

Average stopped delay, in combination with consideration of the volume/capacity ratio, is the most common way to describe the quality of operations at intersections. Setting a target average travel speed for strategic arterials provides a balanced approach from which realistic planning and control schemes for strategic arterials can be obtained.

CONTRASTING PLANNING AND OPERATION OF FREEWAYS WITH THAT OF ARTERIAL STREETS

Classification of highways and streets is discussed in Chapter 2, but further reference to two subcategories of urban principal arterials is made here: freeways and arterial streets. Freeways are defined as divided highway facilities, primarily for through-traffic, upon which access is fully controlled; therefore, there is no interruption of flow by traffic control devices, connections with other facilities are made exclusively by ramps, and grade separations handle conflicting traffic movements. Mobility is their primary function. To satisfy the conditions prescribed by the formal definition, freeways constitute a class of roads for which very specific design criteria are applied. These include

(1) relatively high design speeds that range from 50 to 70 mph, with the upper end of the range more common and with usual speed limits of 55 to 65 mph; and (2) high levels of consistency in design features, which include shoulders and medians, and high standards of driver communication such as high levels of safety and positive guidance. Freeways are further distinguished by relatively high travel speeds and traffic volumes, as shown in the *1985 Highway Capacity Manual* (Ref 16) average travel speed versus flow relationship for freeways.

In contrast, urban arterial streets serve a dual function, providing both land access and mobility. Traffic flow on arterial streets is interrupted by such factors as intersections, traffic controls, pedestrians, driveways, and parking. A wide range of design features, traffic-control techniques, and speeds must be used to provide the required traffic service. The right-of-way along arterial streets normally accommodates pedestrians and a variety of underground and overhead utilities. Because of the need for periodic maintenance, the presence of utilities in the right-of-way will affect traffic operations unless the utilities are carefully managed.

On arterial streets, a very wide range of travel speeds is possible. These can vary from the 50 mph range to 10 mph or less, depending upon traffic conditions and design features of the section under consideration (Ref 33). Figure 3.1 shows typical speed-flow relationships for various types of six-lane road and street facilities. There is a wide range between the productivity of an ordinary city street and that desired for strategic arterials. This is so because the allocation of traffic signal green-time dedicated to the strategic arterial is larger than that usually given to ordinary streets. Productivity is also increased by a reduction in traffic friction. Traffic friction is a function of street parking, access control, how left-turn traffic is accommodated, alignment, provisions for stalled vehicles, amount of truck traffic, and so forth. The range of productivity shown in Figure 3.1 for the strategic arterials suggests about 70 percent allocation of green time.

A maximum flow rate of 1,800 to 2,000 passenger car equivalents per hour per lane is usually considered a reasonable estimate of what can be found on freeways. Flow rates at signalized intersections on arterial streets vary widely, between about 400 to 1,000 through-vehicles per hour per lane.

Another area of contrast is the management of traffic incidents (including accidents, stalled vehicles, debris problems, etc.) and the scheduling of maintenance activities. It has been found that on freeways, users experience more lost-time owing to traffic incidents than to recurrent traffic-volume-induced congestion. Such lost-time can be greatly reduced by responding to incidents with specially trained teams. Similarly, freeway down-time resulting from maintenance and repair work can, by careful planning, be both reduced and deferred to times when traffic flow is light.

It is suggested that some of the design philosophy, operations quality standards, and traffic operations management methods that have been successfully applied to freeways can be transferred to strategic arterials. This can be accomplished by specifically designating selected street segments as strategic arterials and then supporting each designated segment with appropriate design standards, regulations, and legislation. Some of these requirements will be explored in the following chapters, and the concept of designation of strategic arterials is summarized in Chapter 10, as part of a discussion on implementation guidelines.

MOBILITY AND SAFETY

From the above discussion, it seems that the mobility function of the arterial street can be captured by setting ranges for average travel speed and flow rate. Considering the notion that operations on strategic arterials should be intermediate between those of conventional arterials and freeways, a free-flow average travel speed of 45 mph seems appropriate. The corresponding design speed should lie within the higher ranges of those applicable to arterial streets and in the lower ranges of those applicable to freeways (as also shown in Table 2.1, i.e., 45 to 50 mph). Design

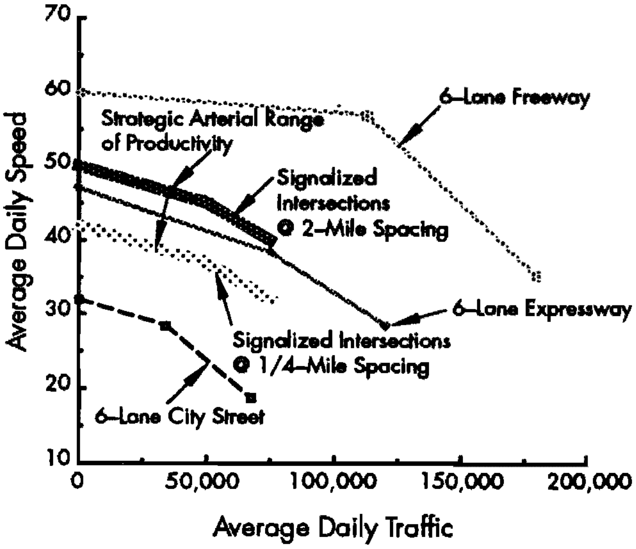


Figure 3.1 **Average speed vs ADT for various types of six-lane highway facilities**

speed is defined as the maximum safe speed that can be maintained by the majority of drivers over a specific section of highway when traffic and weather conditions are so favorable that the design features of the highway govern (based on Ref 18).

With flow rates through signalized intersections the primary constraint, a goal of flow rates of 800 to 1,000 vehicles per hour per lane for strategic arterials is proposed. A minimum of two lanes per direction is required, with more preferred, to accommodate maximum flows of 1,600 to 2,000 vehicles per hour per direction.

Design criteria that can be used to accommodate these speeds and volumes safely are discussed in following chapters.

FACTORS INFLUENCING MOBILITY AND SAFETY ON URBAN STREETS

In this section, an overview is offered of the various factors that determine travel speeds on arterial streets. The factors are analyzed as to their importance, and the potential contribution of the more pertinent factors that affect traffic operations on strategic arterials is evaluated in the following chapters.

The *1985 Highway Capacity Manual* (Ref 16) suggests that the operation of traffic on arterial streets is influenced by three factors: the arterial environment, interaction between vehicles, and the effect of traffic signals. The arterial environment includes the geometric characteristics of the facility and adjacent land uses. The interaction between vehicles is determined by traffic density, vehicle characteristics, turning maneuvers, lane-changing, and the difference in speed between successive vehicles. Traffic control signals require vehicles to stop and to remain stopped for a certain time, after which the vehicles are released in platoons.

The following are the most pertinent factors influencing traffic operations and safety on arterial streets. These factors are the subjects of the following chapters, and specific reference is made to the roles they play in determining the feasibility of establishing a strategic arterial in a given location and to how they can be treated to provide appropriate levels of traffic operations and safety. The factors are:

(1) traffic signals;
(2) geometric features of the facility;
(3) the roadway environment, including driveway access and minor street access;
(4) transit operations;
(5) pedestrian traffic and presence in the right-of-way;
(6) on-street parking and on-street loading; and
(7) incidents, such as accidents and maintenance and construction work.

These factors are interrelated in a complex way. No single simulation model has been developed to fully describe traffic flow on arterial streets. Examples of the effect of the interrelations are shown below.

(1) Mid-block friction can significantly influence the arrival pattern at signalized intersections, which is an important variable in determining intersection delay;
(2) The presence of driveways and frequent intersections tends to increase the number of weaving maneuvers taking place on street sections; and
(3) Adjacent land use not only generates traffic that influences operations but can also cause driver distraction and affect driver perception of safe speeds. The same can apply to other activities, such as bus stops, which attract pedestrians to the right-of-way area.

However, the use of accepted principles in the planning and design of strategic arterials can produce the desired quality of operations. These principles are discussed in the following chapters.

DRIVER EXPECTANCY AND POSITIVE GUIDANCE (REFS 35, 36, 37, 38, 39)

Driver expectancy and positive guidance are functions of the driving' task, which is addressed in the following paragraphs.

The Driving Task

The driving task has three levels: control, guidance, and navigation. According to related literature, these levels and their associated actions can be prioritized based on a scale of complexity and primacy. The degree of complexity is a function of the time taken to process information, to react, and to respond. Primacy is related to the importance of each level of the driving task, with specific regard to the consequences of error. The scale of complexity increases from control through guidance through navigation. Primacy decreases in the same direction.

Control is the response of a driver's interaction with the motion of the vehicle and its controls, such as the brakes, throttle, and steering mechanism. The driver responds to the feedback coming from the controls, the instrument displays, and the vehicle's motion. Although complexity at the control level is low, the primacy of the control task is high, and an error will increase the probability of an accident.

Guidance is the ability to select from competing choices a safe speed and an expedient path of travel. Guidance requires judgment, knowledge, and the capacity to predict. In order to exercise guidance, the driver receives input from the immediate environment. The driver's environment includes the roadway within sight, adjacent property, weather, light conditions, surrounding traffic, and traffic control devices such as signals, regulatory and warning signs, and markings.

Navigation is the action associated with planning and executing a trip from origin to destination. Information necessary for navigation comes from personal experience, maps, verbal directions, guide signs, and landmarks. Information analysis and trip planning can be complex and the time between receiving information and responding to it can be long. Error on the navigation level has a lower primacy but can and does affect control, guidance, and perhaps safety. Erratic control and maneuvering are common indicators of anxiety and uncertainty on the navigation level.

Much can be done to assist drivers in guidance and navigation by supplying information (both directly and indirectly) to the driver at the right time and at the right place. The information should be clear, relevant, timely, and unambiguous, in the interest of rapid processing. The result of such assistance will be improved safety and smoother traffic operations. Examples are (1) explicit information, obtained from signs, signals, markings, and maps, and (2) implicit information, such as that obtained from the in-situ roadway and its environment.

Expectancy

Reaction time is the time between detecting a stimulus and taking action. Reaction time varies among individuals and is strongly related to decision complexity, information content, and expectancy. Measurements of brake reaction time indicate that the average reaction time for an expected signal is about two-thirds of a second. When the signal was unexpected, reaction time increased by 35 percent, with some drivers taking up to 2.7 seconds (Ref 18).

Expectancy relates to a driver's readiness to respond to situations, events, and information in a predictable and successful way. Expectancy influences the speed and accuracy of driver-information processing. Roadway configuration, traffic operations, and traffic control devices that are in harmony with an expected situation, or a sequence of situations, reinforce expectancy. Reinforcement enables drivers to respond quickly, efficiently, and accurately. At the guidance level, reinforcement comes from highway configuration and traffic operations. At the navigation level, route markings and guide signs are relevant. Reinforcement is also affected by the interaction agreement between guidance level and navigation level information.

There are two types of driver expectancies. The first is long term, *a priori*, based on past experience, culture, and learning. Highway designers often have to consider whether the great majority of drivers on a facility are repeat users of the facility, such as those on commuting routes, or whether they are occasional users having a low *a priori* expectancy, such as those on recreational routes.

The second type of expectancy is short term, *ad hoc*, involving those expectations that drivers formulate from site-specific practices and situations encountered while traveling. An example is the expectation of an EXIT guide sign at the next exit ramp following an advance warning GUIDE sign advertising the particular exit. Another common example is the expectation, upon entering a curved road, that the curvature of road *will not* become sharper beyond the sight distance at the end of the initial tangent-to-curve transition area. Not meeting this expectancy creates a potentially dangerous situation and should be avoided if possible.

There is an opportunity for designers of strategic arterials to reinforce driver expectancy by addressing geometric design details and traffic operations standards. Special treatment of intersection design, median barrier treatment, signalization, allocation of signal green-time, U-turn provisions, signing, and provisions for auxiliary lanes are elements of design and operations which can be treated to enhance driver expectancy. These are addressed in later chapters.

Positive Guidance

Information is provided to the driver by the roadway and its environment, traffic control devices, markings and delineators, regulatory and warning signs, and traffic conditions. Positive guidance information is provided when information is presented unequivocally, unambiguously, and conspicuously enough to meet the decision-sight-distance criteria and improve the probability of appropriate speed and path decisions (Ref 37).

One of the most powerful ways to provide positive guidance and to create, improve, and utilize driver expectancy is through the use of *consistent* design over a considerable length of highway. In the case of strategic arterials, the aim is to provide consistency over the full length of each facility and to standardize design for all similar arterials as far as possible. The design standards adopted for the Interstate Freeway System are a good example.

Specific ways to provide positive guidance and to utilize the concept of driver expectancy on strategic arterials include:

(1) consistent use of geometric alignment, both vertical and horizontal, to suit a constant design speed over the full length of arterial;
(2) consistent treatment of side streets and driveways to minimize their effect on the operation of through-traffic;
(3) consistent design and use of guide signs;
(4) consistent intersection layout, including such aspects as lane usage and signal phasing for both at-grade and grade-separated intersections;
(5) treatment of medians; and
(6) consistent standards for handling turning movements at intersections.

SOCIAL AND POLITICAL ISSUES

Although the main subject of this report is the development of design criteria for strategic arterial streets, political and social factors play a role in the successful implementation of all infrastructure projects and therefore require consideration. To some extent, planners and designers can mitigate or avoid some of the adverse conditions stemming from political, public, and social influences. Some of these issues can also be addressed through the public level of planning involving negotiations and hearings. Some design features and traffic operations which may stimulate controversy are:

(1) restricting of access to properties, specifically business properties;
(2) introducing high-volume, high-speed traffic into neighborhoods, and, in contrast, reducing the traffic on streets fronting some business properties;
(3) making roadway changes that require more circuitous routes of travel;
(4) planning visually intrusive structures, such as grade separations and median barriers;
(5) providing safety of travel, including perceived safety of pedestrians;
(6) increasing taxes to finance projects;
(7) causing of noise and emissions intrusion from increased traffic; and
(8) causing unfavorable land use changes caused by changes in traffic flow.

Political issues cover not only public reaction, often reflected in the decisions made by officials, but also the interaction between agencies and authorities involved in providing a transportation infrastructure. These issues often include (1) establishing specific standards of design, (2) determining which agency is to implement and manage the project and what is defining its authority, and (3) agreeing on relevant issues when one roadway project traverses the areas of several local authorities.

CHAPTER 4. EXAMPLES OF URBAN STREET PLANNING AND DESIGN APPLICABLE TO STRATEGIC ARTERIAL STREETS

INTRODUCTION

The following is a presentation of case studies describing applications of arterial street design features by three public transportation agencies. The highlighted design features are: access control, median treatments, treatments of major intersections, and driver guidance. Also described are practices with respect to arterial street location and the effect of specific geometrical design treatments on land use.

The guidelines derived by this study were influenced by the design practices of the public agencies cited herein.

The three public agencies cited are: the New Jersey Department of Transportation, the Orange County Transportation Commission (California), and the Colorado Department of Transportation. The design practices of these agencies which are considered applicable to this study are described in the following paragraphs.

THE NEW JERSEY DEPARTMENT OF TRANSPORTATION USE OF MEDIAN BARRIERS ON ARTERIAL HIGHWAYS AND STREETS

This description of New Jersey Department of Transportation (NJDOT) practice is based on field observations and conversations with and materials obtained from representatives of the NJDOT. The field observations were made at highway sites where geometric and traffic control features have been modified to increase efficiency and safety. These sites, for the most part, were in urban or suburban areas along age-old highway routes serving intensely developed areas.

Description

The NJDOT has installed a concrete median barrier (developed by NJDOT and now known as the New Jersey barrier) on approximately 287 of the 1,400 miles of the state highway system. A sizable proportion of these highway routes are, functionally speaking, urban arterial streets. These highways have relatively infrequent and randomly spaced at-grade signalized intersections, and the abutting property has direct access.

In addition to installing the median barrier, the NJDOT also designed the intersections along these routes to exclude left turns from the barrier-divided highways. Left-turn movements from the barrier-divided highways to crossing roads are accommodated by "jug-handle turns" and by right-hand "reverse" loops. Left turns from a cross street to the barrier-divided highway are permitted. The directionality of traffic movements at these intersections is the same as that at freeway diamond and cloverleaf interchanges. To increase opportunities to access properties on both sides of the streets, provisions for U-turns are made either separately or at street intersections. Figures 4.1, 4.2, 4.3, and 4.4 illustrate the different types of traffic movements permitted along these barrier-divided roads.

Enhanced safety was the initial reason for installing the median barrier. The NJDOT officials subsequently reported a noticeable decrease in the frequency of accidents. At the same time, the elimination of left-turning vehicles at mid-block locations and intersections had significant beneficial effects on traffic operations. Warrants for the installation of the system are based primarily on accident experience, particularly accidents associated with left-turning movements. The AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers (Ref 62) is also used as a guide. This document has recently been superseded by the AASHTO Roadside Design Guide (Ref 63).

The advantages and consequences of the installation of the median barrier are briefly summarized here.

(1) The barrier virtually eliminates the possibility of head-on collisions. The exposed barrier terminal ends at at-grade intersections are not considered particularly hazardous. It was noted that crash cushions were not installed at the barrier ends. The cushions were considered intrusive because they created a larger

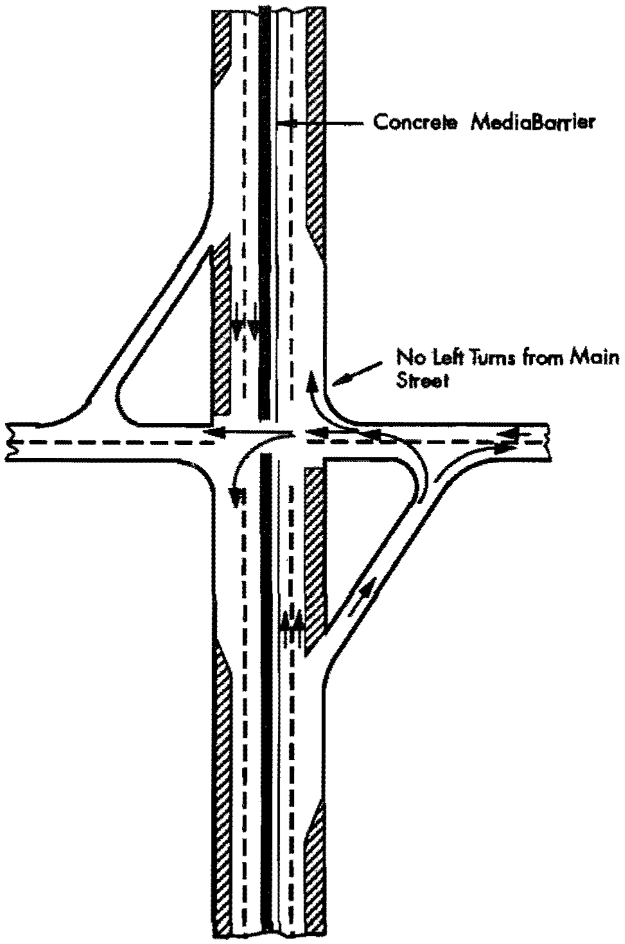


Figure 4.1 Jug-handle configuration

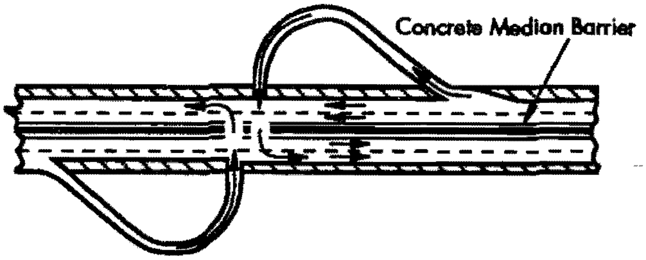


Figure 4.2 Jug-handle configuration for U-turns only

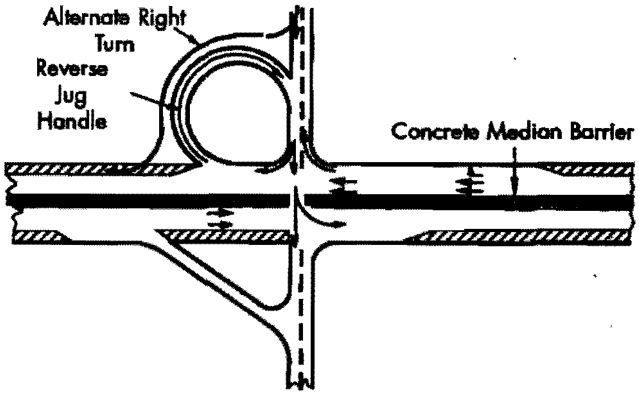


Figure 4.3 Reverse jug-handle configuration

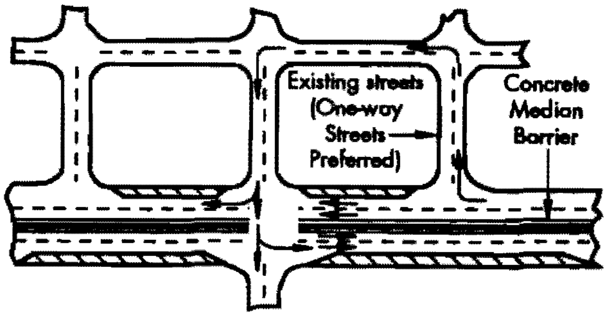


Figure 4.4 Indirect left and U-turns, using intersecting streets

target after an impact and consequently were not considered cost-effective. Along the narrow right-of-way of these routes, utility poles occur very frequently along and closely adjacent to the curb line. The presence of so many potential collision targets suggests that the absence of crash cushions at the ends of barrier strings would not have any measurable effect on overall safety.

(2) Medial friction of the opposing traffic streams found on two-direction streets is greatly reduced. The median barrier requires less right-of-way width than do normal curbed medians with protected left-turn lanes.

(3) The barrier prevents mid-block left turns to driveways, without continuous law enforcement, as may be required when only a painted median and regulatory signs are used. Removing mid-block left turns from the leftmost, "fast" lane greatly reduces weaving into and from this lane, which eliminates major factors contributing to traffic delay and accidents.

(4) Left turns at intersections are a major cause of intersection delay, and their removal improves intersection capacity and quality of operations. Eliminating left turns may reduce the number of signal phases needed, and it also reduces queuing.

(5) Accident frequency and severity are decreased by the reduced speed differential between traffic in the left lane and other lanes resulting from elimination of left-turning traffic. This decrease in turn results in a reduction of traffic delay caused by such incidents and thereby enhances the facility reliability.

(6) The presence of the median barrier and the left-turn exclusion communicates the character of the facility and is an excellent example of positive guidance.

(7) Land use has adjusted to the turning movement restrictions and property access at no

apparent loss in value. Some property interests object to the traffic restrictions imposed by the installation of the median barrier and elimination of left turns. However, there is a trade-off in increased capacity and quality of service along the barrier highway which may make property more valuable. This increased value results as property competes in an enlarged market area. Clientele potential increases as a result of improved, wider-ranging traffic service and more reliable traffic operations.

Provision for Turning Movements

Discussion with officials of the NJDOT indicated that provision for turning movements is, wherever possible, made by providing "jug-handle" loops. Configurations used are:

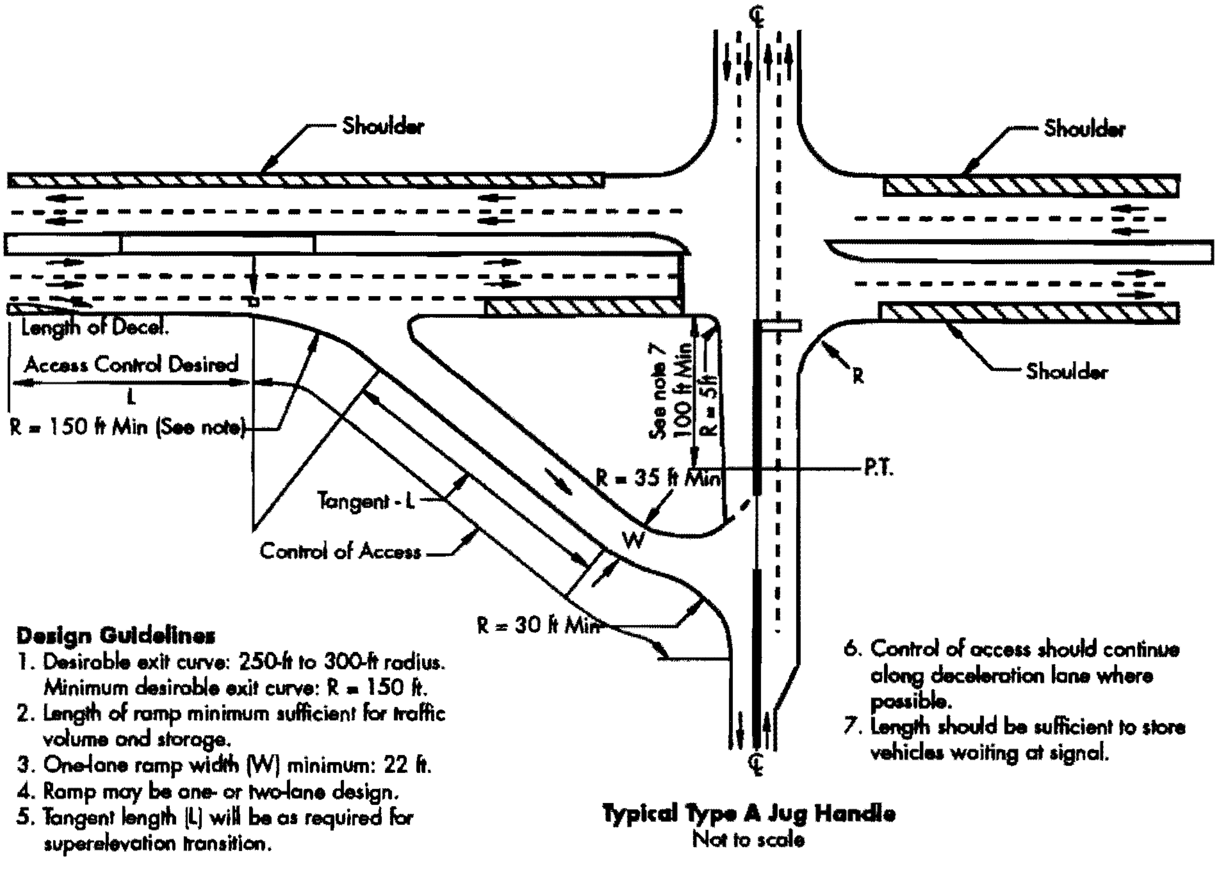
(1) The reverse loop has the disadvantage of possibly being initially confusing in that it takes left-turning traffic twice through the intersection, but has a decided benefit in that *all* turns to the cross street are entered from the right lane.

(2) In some cases, the area within loops has been designated for development. The NJDOT experience with direct land access from the loops has indicated that access in such a way is less than desirable.

(3) Provision for U-turns is essential in order to offer equitable land access and is necessary at least every 0.5 mile.

(4) Where right-of-way is difficult to obtain and existing streets are suitable, existing streets can serve as loops (see Figures 4.5a, 4.5b, and 4.5c).

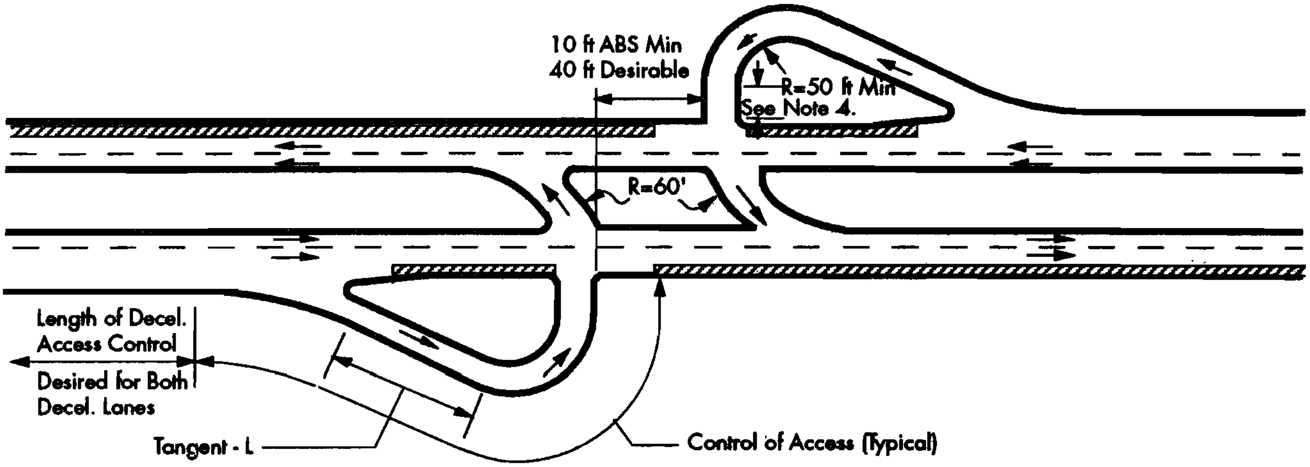
Access to indirect turning facilities is well marked by signs, as shown in Figure 4.6. The NJDOT ascribes part of the success of the barrier-divided system to the fact that most drivers are familiar with the traffic operation conventions on these roads. An interesting aspect is that through careful application of the elements of the system, drivers are reportedly associating the presence of the median barrier with the provision of the indirect turning movements—an excellent example of reinforcing driver expectancy by identification with the roadway cross section. This reinforcement is further enhanced by changing from a concrete



Design Guidelines
1. Desirable exit curve: 250-ft to 300-ft radius. Minimum desirable exit curve: R = 150 ft.
2. Length of ramp minimum sufficient for traffic volume and storage.
3. One-lane ramp width (W) minimum: 22 ft.
4. Ramp may be one- or two-lane design.
5. Tangent length (L) will be as required for superelevation transition.
6. Control of access should continue along deceleration lane where possible.
7. Length should be sufficient to store vehicles waiting at signal.

Typical Type A Jug Handle
Not to scale

Figure 4.5a Typical type A jug handle



Design Guidelines

1. Desirable exit curve: 250-ft to 300-ft radius. Minimum desirable exit curve: 150-ft radius.
2. Length of ramp minimum sufficient for traffic volume and storage.
3. Tangent distance: 25 ft absolute minimum, 100 ft desirable.
4. Ramp may be of one-lane or two-lane design.
5. Tangent length (L) will be as required for superelevation transition.
6. Control of access should continue along deceleration lane, where possible.

Typical Type B Jug Handle
Not to Scale

Figure 4.5b Typical type B jug handle

median barrier to a conventional curbed median well in advance of intersections where left turns and U-turns are permitted.

Signals

Coordination

Traffic signals along the subject arterials are connected for coordination, with coordination speeds compatible with speed limits and two-way coordination where applicable. Two-way coordination is also the criterion by which the minimum allowable spacing between intersections of 500 to 1,000 feet is obtained.

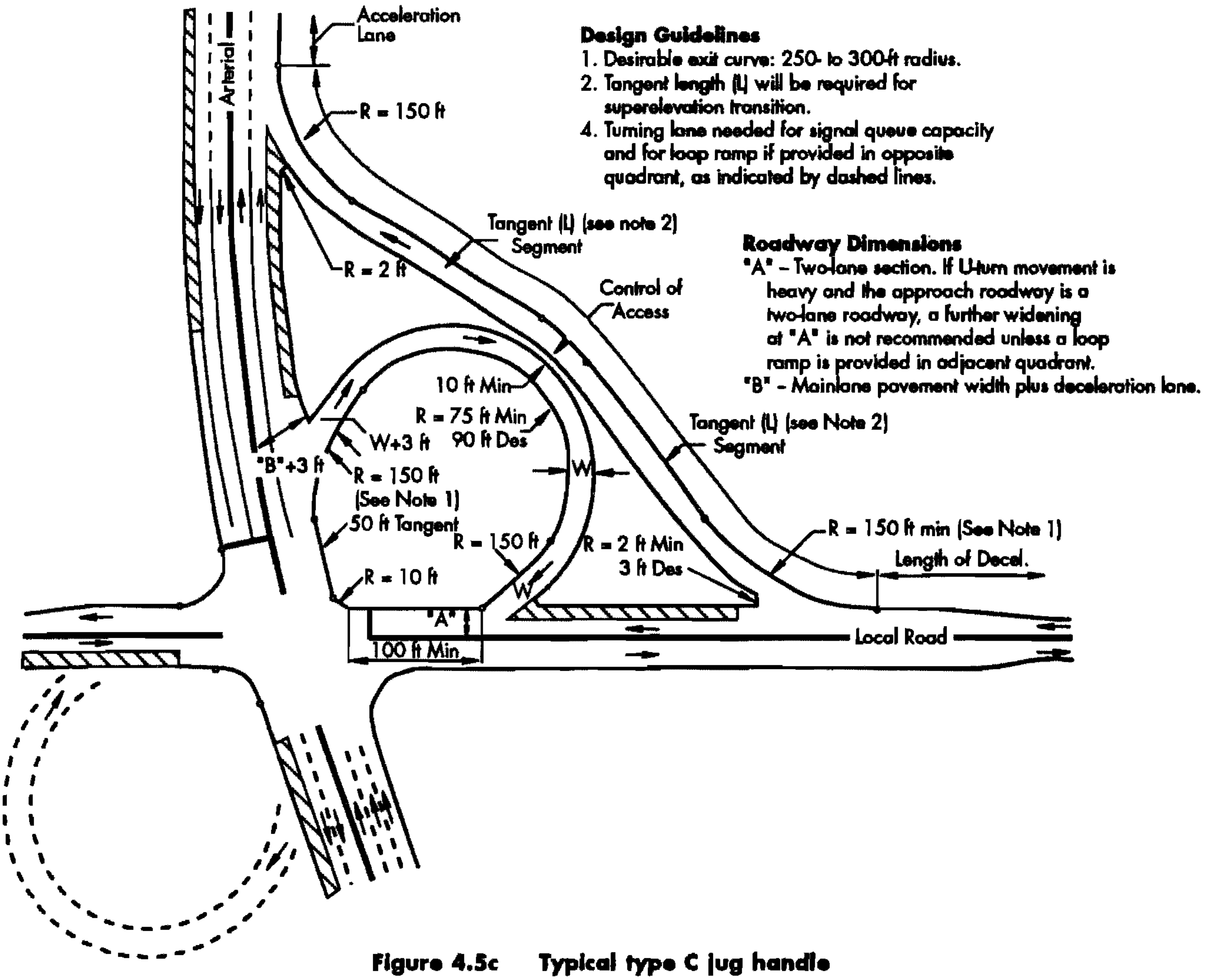
Phases and Green-Time Allocation

All intersections on the barrier-divided arterials are equipped with semi-actuated signal controls, with green intervals resting on the arterials. Minimum cycle lengths are currently set to 90 seconds for off-peak periods and to 120 seconds for peak periods. Two-phased operations are the norm, with minimum green-times allocated in accordance with estimated demand volumes. Some intersections have an additional phase to allow for left turns from the crossing street to the arterial. The no-left-turn rule precludes provisions for left turns directly from the median-divided arterial to the cross streets. Signal heads are placed according to standard practice. Exceptions are signal heads placed in advance of intersections to reduce the possibility of intersection signals being obscured by larger vehicles.

Other Aspects Pertaining to Geometrics and Operations

As a general guide, the NJDOT provides a 1- to 3-foot-wide inside shoulder (included in the 4- to 8-foot-wide median) which is delineated by a painted line adjacent to the median barrier. Wherever feasible, the inside shoulder along left-turning roads is widened to enhance sight distance. NJDOT officials reported that more accidents are experienced where the median shoulder is narrow.

Speed limits are set using the 85th percentile speed as a guide. Speed limits as high as 55 mph are used for some sections; however, in heavily developed areas, limits as low as 35 mph have been posted. Higher speed limits are used on sections where little direct land access is present, and these sections generally have a paved, 10-foot-wide, right-side auxiliary lane. This shoulder enhances safety and offers the opportunity for vehicles to enter driveways using the shoulder as a



Design Guidelines

1. Desirable exit curve: 250- to 300-ft radius.
2. Tangent length (L) will be required for superelevation transition.
4. Turning lane needed for signal queue capacity and for loop ramp if provided in opposite quadrant, as indicated by dashed lines.

Roadway Dimensions

"A" – Two-lane section. If U-turn movement is heavy and the approach roadway is a two-lane roadway, a further widening at "A" is not recommended unless a loop ramp is provided in adjacent quadrant.

"B" – Mainlane pavement width plus deceleration lane.

Figure 4.5c Typical type C jug handle

deceleration lane; in this way, the shoulder essentially serves as a continuous right-turn lane. The adverse effect of a large speed differential between passing vehicles and turning vehicles is thus minimized. The shoulder usually becomes a right-turn deceleration lane on approaches to an intersection, where a jug-handle turn has been provided. At some locations, where there is sufficient right-of-way, an additional lane is provided through the signalized intersection.

Grade separations have been installed at some intersections, but this is not currently an area of primary interest to the NJDOT. In cases where traffic impact studies have shown that traffic generated by proposed developments will overextend existing intersection capacity, developers are financing or participating in the financing of grade separations.

NJDOT officials reported some problems with pedestrians wishing to cross roads where the barriers have been installed, especially from an enforcement viewpoint. Even where pedestrian bridges have been provided, some pedestrians still prefer to cross at-grade and would rather negotiate the traffic and the median barrier than use the bridge. Legislation to ensure provision for mobility-impaired persons has made the installation of pedestrian overpasses—without entering into high expenditure and right-of-way acquisition—very difficult.

State law in New Jersey prohibits truck traffic from the left-most lane where there are three or more lanes in a direction. This law is asserted by appropriately worded signs along roads with six or more lanes. This prohibition, with the elimination of left-turn traffic from the inner lanes, significantly improves the quality of traffic flow.

Land Use

A wide variety of land-use types are present along these median-divided arterials. Commercial enterprises that are dependent on drop-in traffic—filling stations or fast food outlets, for example—are found along the roads, as are many light

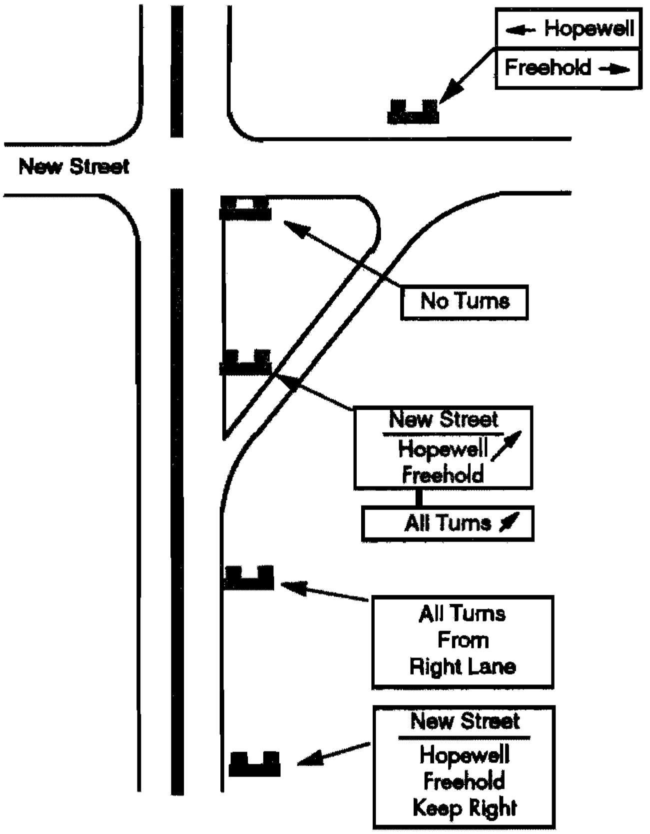


Figure 4.6 Signing for jug-handle turns

industrial developments and motels. Several shopping malls front onto the roads. In such cases, special provision has been made to accommodate the traffic by additional acceleration and deceleration lanes, U-turn accommodation, and additional direction signs at the points of indirect left turns. There is no evidence that the median barrier and indirect left turns have inhibited traffic-dependent commercial development.

Public and Political Acceptance

As expected, there were numerous objections to the median barrier retrofits. Political acceptance for the system has been obtained by stressing the potential safety improvements. Objections from the commercial sector have mostly been based on the decrease in access associated with the system. In cases where the system has been installed, as much as a 25 percent decrease in customers was experienced in the first year by some enterprises, but after that time, previous levels were restored or exceeded. Subsequent reaction from businesses reflects the opinion that business has benefited from enhanced traffic safety. According to New Jersey law, a reduction in access to passing traffic is "non-compensatory." This stipulation has assisted in regulating control of access. In residential areas, objections were based on the possible visual intrusion of the barrier and accompanying effects on the community. The NJDOT has been fortunate in that the system has been in place in several locations for some time, and that such locations serve as examples to reassure concerned citizens. In some areas where development is predominantly residential, a lower barrier—basically a narrow-barrier curbed median—has been installed, creating less visual intrusion than the standard taller barrier.

Conclusion

The main aim of the installation of continuous median barriers on arterial streets in New Jersey has been improvement in safety, but the installation also has benefited traffic operations. The separation of opposing traffic, the effective management of access, and the effective elimination of left turns at intersections have significant benefits to traffic operations. The New Jersey experience is thus of specific importance. This experience shows that continuous median barriers can be successfully used on urban arterials, with positive effects far outweighing negative effects, and invalidating notions of extreme adverse effect on commercial developments.

Most of the important elements needed to create a strategic arterial street are present along New Jersey's barrier-divided highways. The principal shortcoming is that these improvements were retrofits to old highway routes with narrow right-of-way, which has caused some of the design elements to be less than desirable. The three roadway elements which had to be minimized or sacrificed in order to obtain the maximum number of traffic lanes, in order of priority, were the median width, the lane width, and provisions for the right-hand auxiliary lane-shoulder.

THE ORANGE COUNTY SUPER STREETS PROJECT

Background

The Super Street concept was identified in studies by the Orange County Transportation Commission (OCTC) in the mid-1970's as a partial solution to the travel demands expected on the Orange County freeway and arterial street system. In 1982, the High Flow Arterial Concept Feasibility Study (Ref 10) identified the special role of flyovers and signal coordination as feasible options to improve traffic flow and increase capacity. The 1982 study utilized the TRANSYT-6 macroscopic simulation model to evaluate the effects of the projected improvements. In 1984 the OCTC identified a

220-mile Super Street arterial network and selected Beach Boulevard as a demonstration project to be the County's first Super Street. Work has also progressed on the planning for two other streets, namely Katella Avenue and Imperial Highway.

The Beach Boulevard Demonstration Project

The portion of Beach Boulevard selected to be a Super Street is approximately 19.5 miles long. Caltrans is responsible for the operations and maintenance of the facility. The street passes through intensely commercialized property in 10 incorporated cities. The roadway generally consists of six through-travel lanes, divided by a median with provisions for two-lane left-turns. Right-of-way widths vary between 108 and 192 feet. Traffic counts taken in 1985 showed that 15 of the 40 major intersections along the route operated at an unacceptable level of service, in that peak-period demands exceeded capacity. Projections indicated that this number will increase to 24 by the year 2005. Beach Boulevard carries about 50,000 to 80,000 vehicles per day, depending on the section, on six lanes, with about 8.5 percent of daily traffic during the peak hour. The centerline of the section of Beach Boulevard designated for treatment is basically straight, with continuous roadside development. However, the density of the development is relatively low compared with that of typical strip developments in the City of Los Angeles. Current speed limits along the route vary between 45 and 50 mph, although actual speeds are primarily controlled by traffic conditions and drivers' perceptions of safe speed.

Improvement Alternatives

Improvements for each intersection and mid-block area were selected from a hierarchy of improvement classes:

(1) a no-build alternative;
(2) a Transportation System Management (TSM) alternative, which included low-cost improvements such as signal coordination, bus turnouts, and roadway restriping;
(3) a moderate-cost alternative, which included widening of intersections within the existing right-of-way, parking turnouts, driveway consolidation, median closures, and turning movement restrictions; and
(4) a high-cost option, which would require additional right-of-way for intersections and mid-block street widening for the installation of grade separations.

The criteria for improvement selection were:

(1) reducing existing peak-hour volume/capacity ratio to below 0.90;
(2) minimizing the need for right-of-way acquisition;
(3) providing a consistent number of through-lanes;
(4) optimizing cost-effectiveness;
(5) minimizing negative environmental impacts; and
(6) maximizing the project's long-term benefits, while minimizing temporary adverse economic impacts, referring mainly to business enterprises along the route.

Proposed Improvements

The proposed improvements included:

(1) intersection widening, within the existing right-of-way, at 13 locations;
(2) intersection widening, requiring new right-of-way, at 18 locations;
(3) 24-hour parking restrictions;
(4) restriping most of the 19.5 miles to four through- lanes, requiring localized right-of-way widening, with a short section to be six lanes;
(5) signal coordination over the whole length;
(6) bus turnouts installed over the whole length;
(7) access control, median closures, and driveway consolidation at selected locations;
(8) roadway improvement such as drainage and pavement rehabilitation, where needed; and
(9) recommendation of three grade separations, two required within 5 years and another within 15 years.

Grade separations were also evaluated for five other locations but were found not to be cost-effective. Even in the early stages, the two more urgent grade separations were opposed by the two local councils involved, and intersection-widening alternatives were accepted. A decision on the third grade separation was deferred pending additional engineering and environmental study.

An extensive public participation program was developed for the Beach Boulevard project, to ensure dissemination of information and to build consensus. Public participation activities included:

(1) direct mail notification of over 3,000 businesses, property owners, and residents at specific milestone dates;
(2) community information and City Council briefings;

(3) individual meetings with affected businesses, property owners, and residents; and
(4) establishment of a Policy Advisory Committee and a Technical Advisory Committee, both of which included representatives of each affected public agency.

Current Status

No construction on any of the Super Streets had started as of June 1990. In early 1990, a plan to fund the Super Street project by a local one-cent sales tax increase was defeated in an election. Funding for these programs is currently provided by interest from a fund built from taxes destined for transit improvements. The OCTC is, however, actively searching for additional funding sources—including endeavoring to obtain part of the California State gas tax.

Plans to incorporate grade separations at some intersections have been all but canceled because of strong opposition from businesses, particularly those on corner properties, who fear loss of convenient access and visibility.

Conclusion

The preceding description highlights the importance of political and social factors in the process of negotiating and planning for arterial street improvements. The principal aim of the planners is to make maximum use of the community's valuable existing rights-of-way access along Beach Boulevard. Whether or not the utility of this asset can be fully adapted remains to be seen. As discussed, the most productive part of the plan is a proposal to install grade separations at several critical intersections. This part of the plan also generated the most opposition, which resulted in the more modest proposal to enhance the quality of traffic flow by adopting TSM-type improvements, which are considered cost-effective and less demanding of additional right-of-way. The fact remains that the existing right-of-way assets along the 19.5-mile corridor cannot be fully exploited unless the critical grade separations are installed. The most noticeable side effect of omitting the grade separations will be to greatly reduce the ability of Beach Boulevard to effectively serve the longer trip demands. One of the objectives of the improvements to Beach Boulevard was to supplement the freeway system by providing attractive alternate travel routes. This objective will not be fully met without the grade separations.

The ad hoc selection of improvement alternatives and the opposition to the use of grade separations have almost reduced the Beach Boulevard project to the application of a series of TSM measures. What is commendable, however, is the consistent application of these measures to long arterial sections. The strategic arterial concept suggests rigorous application of standards, commensurate with desired operational characteristics.

STATE OF COLORADO ACCESS CODE AND ACCESS CONTROL DEMONSTRATION PROJECT

Background

The Access Control Demonstration Project, conducted by the Colorado Department of Highways, was sponsored by the Federal Highway Administration. The study objective was to determine the cost-effectiveness of controlling access to maintain a higher level of service as an alternative to widening and building new arterials. In 1977, the Colorado Highway Commission initiated a policy to establish access control for all highways under its jurisdiction and to promulgate policies and procedures for the proper exercise of those controls. The Department was further ordered to (1) develop a highway access code of rules and regulations, (2) develop access plans for every state highway construction program, (3) classify each segment of the state highway system into a hierarchy of access control based on needs, (4) improve and expand the access permit program, and (5) improve coordination with local governments and developers in order to lessen the impact of development on the state highway system through good local planning. In response to the directive, a new State Highway Access Code went into effect in the summer of 1981.

The Colorado State Highway Access Code

The purpose of the code is: to provide the procedures and standards necessary to protect the public health, safety, and welfare; to maintain smooth traffic flow; to maintain highway right-of-way drainage; and to protect the functional level of public highways while meeting state, local, and private transportation needs and interests. Many aspects of the code rely on applicable access laws. The Access Code is partly based on the 1983 AASHTO Policy (Ref 18) and endeavors to "preserve the functional integrity of highways."

Access Law

The premise of access law in Colorado is that all properties are entitled to reasonable access to the general street system. Any road to which property has access is controlled by public authorities through their police powers. Regulations allow denial of access so long as reasonable alternative access is provided or exists. The Colorado State Department of Highways and local governments are authorized to regulate vehicular access to and from any public highway under their respective jurisdiction. In a 1985 amendment to the Colorado Highway Access Law, all state highways were declared to be controlled-access facilities.

The Access Code is further divided into three sections that deal with administration of the code, access category standards, and design standards and specification. The most important elements of the Code, along with those that provide direction for the development of strategic arterials, are summarized below.

Administration

Each highway is assigned an access category from the categories which are based on the characteristics of the highway:

(1) existing and projected traffic volumes,
(2) local transportation plans and needs,
(3) character of land use adjoining the highway,
(4) local land use plans and zoning,
(5) availability of vehicular access from local streets, and
(6) availability of reasonable access from public roads other than those on the highway system.

The Access Code describes the administrative permitting process involved, the appeals, and the variation procedures, as well as the process guiding the actual construction. One of the more important regulations is that the construction will be subject to inspection by the Colorado Highway Department and, where required, property and improvements necessary for proper access shall be dedicated without cost to the department. Improvements may include curbs, gutters, sidewalks, drainage structures, and auxiliary lanes on public right-of-way.

Of specific importance is that reconstruction, relocation, or conformance to the Access Code can be required by the Colorado Highway Department when there is expected change in the use of the access because of a change of the property use. Change criteria include an increase of 20 percent or more in any of the following: traffic volumes; the number of heavy vehicles using the access; turning movements; or modifications on the property that cause entering vehicles to be restricted, to queue, or to hesitate on the highway. Another criterion is the non-use of the parcel of land for more than 4 years. The Colorado Highway Department or an appropriate local government is also authorized, at its own discretion, to develop an access-control plan for the purpose of bringing a portion of highway into conformance with the access category of the highway.

Access Category Standards

All highways are designated as one of five categories, which are based on the functional characteristics of the highway, and each is assigned a set of applicable design standards. The aim of the design standards is to ensure that the highway will continue to function at the level assigned and that access permit requirements meet the standards.

Category 1. Highways in this category have the capability to carry high-speed, high-volume traffic over long distances. Examples would be interstate, interregional, intercity, and intra-metropolitan highways. Suitable design standards would separate all opposing movements using grade and median separation, and would restrict access to the use of directional ramps only.

Category 2. Highways in this category are similar to those in Category 1, although at-grade intersections may be allowed. An example may be the first-stage construction of a Category 1 facility. Design standards include a 55-mph speed limit, intersection spacing in excess of 1 mile, and strict control of land access unless there are no alternatives available, in which case right turns only at driveways are strongly favored. Turning movements are controlled by physical constraints such as grade separation and medians and by traffic signals that are programmed to ensure high mobility—for example, coordination to allow a minimum speed of 45 mph, and a desirable progression green band width of 50 percent of the minimum green interval.

Category 3. These highways carry medium-to-high volumes at medium-to-high speeds. Mobility is favored over access. Design standards provide for speed limits of 45 mph in developed areas and 55 mph in undeveloped areas. Intersection spacing is restricted to 0.5 mile. Right turns only, at driveways, are favored, and signal progression green band widths of 40 percent or more are desired, with a minimum of 30 percent.

Category 4. Category 4 highways carry moderate traffic volumes at moderate travel speeds. Medium- to short-distance trips are served, and a balance between mobility and access needs is sought. Design standards are based upon a 35-mph speed limit. Land access is subject to some restrictions, such as right turns only at unsignalized access points. Preferable minimum spacing of major access points and intersections is 0.5 mile. A signal progression green band width of 30 percent is desired, with a minimum of 20 percent.

Category 5. This category contains roads that primarily function to provide access and are not designed to accommodate long-distance trips or high volumes. As far as State-controlled highways are concerned, frontage or service roads are examples. Design standards pertain almost exclusively to safety requirements.

Design Standards and Specification

Driveways accessible from highways must conform to standards for the highway access category and traffic volume criteria which address both through and driveway flows. The DHV is based on generation rates offered by *Trip Generation*, published by the Institute of Traffic Engineers (Ref 146). The values to be used are for the final or last-phase build-out development, and for the twentieth-year prediction of highway traffic volumes. The design standards cover driveway widths, curb return radii, speed-change lanes, required sight distance, drainage details, and surfacing and maintenance requirements.

Access Control Demonstration Project

Two highway sections, located in the southeast suburban part of the Denver metropolitan area, were chosen to demonstrate the application of the access code. The project covered 4.36 miles of State Highway 88 (along which the developments are predominantly business with offices, light industrial warehouses, and some retail) and 5.16 miles of State Highway 83 (along which the developments are primarily residential with supporting retail and services).

A study team was formed of representatives from the planning and engineering departments of local authorities, the Colorado Department of Highways, two consulting engineering firms, and the Federal Highway Administration. The team made presentations concerning the function and details of the proposed project to elected city and county officials. The presentations assisted the officials in making land use decisions and in understanding staff recommendations concerning zoning. The team convened a public meeting soon after the commencement of the project in order to inform interested citizens about the project and to give the opportunity for questions and concerns to be raised. While the concept plan was being developed, approximately 70 smaller meetings were held with various individuals and groups to work out conflicts and disagreements. A final public meeting was held at the end of the planning phase, and it was reported that the final meeting went reasonably smoothly because of the close previous contact with individuals and groups.

The project design standards required that signalized intersections be spaced at 0.5-mile intervals in order to permit two-way progressive signal timing and moderate two-way travel speeds. The existing block patterns fitted this 0.5-mile spacing. The project design standards also allowed for access at intervals of 0.25 mile, and where this access point is *not* at a signalized intersection, *only right* turns into and from the access point are allowed. This access restriction is enforced by a continuous curbed median. Auxiliary turn lanes are provided at every access point along the highway, and in several locations these are continuous auxiliary lanes. The jug-handle indirect left-turn design was considered but not selected; rather, double left-turn lanes are installed at all major intersections to reduce left-turn signal time.

Where existing access was reconstructed or relocated, plans were presented to landowners. However, only relatively minor revisions were necessary. Right-of-way and easements were acquired to allow for service road construction and access relocation. Local government support was used to establish a local and collector street system to supplement the arterial system. Through local government controls and authority, all developing properties were ensured of internal circulation with access at predetermined locations, and denied access to the arterials where alternative accesses were available.

Unfortunately, no traditional "before-and-after" study was performed because of changes in land use and transportation demands and the short time available between completion of the project and reporting the results. The TRANSYT model was used to establish signal timings and to compare expected travel speeds, travel time, and delay time for the access-controlled scenario and the unrestricted scenario. It was found that, with demand at 95 percent of capacity, predicted average travel speed increased from 12.8 mph (for the unrestricted case) to 22.3 mph (for the access-controlled case). Traffic conflict analysis was used to illustrate the safety benefits of the project.

Public responses to the project were measured through structured interviews with property owners, residents, and government staff. Results revealed that most of the dissatisfaction with the implementation of access control came from the business/retail sector, specifically those who lost left-turn access. Business owners who had indirect access before the project was implemented gave favorable or indifferent ratings to the project. In some cases the response of business owners toward the project was tainted by their loss of business during the construction period. Generally, older-style small businesses on small lots, which had no internal circulation and little improved parking space, suffered most. The project was received well by residents of the area, who mostly felt that reduced through-traffic and increased safety outweighed the inconvenience of more circuitous routes. The development sector received the project well, with the primary concern being future property access. Indirect benefits to local governments, through increased safety and capacity, were translated into growth, increased land values, and reduced capital expenditure through better utilization of an existing facility.

CONCLUSION

The Colorado Access Code is an excellent example of applying strict standards of highway access that are commensurate with the functional highway class. The combination of other characteristics—such as traffic signal operations criteria—with the highway classification is also of special importance. In addition, the attention to measures supporting the functional integrity of the highway facilities is of specific significance.

The demonstration project covered facilities located on relatively wide right-of-way and within low-density land use, and did not fully challenge the requirements and practicality of the Access Code. Moreover, according to the TRANSYT traffic operations analysis cited above, the access control provisions do permit a peak-hour travel speed increase of nearly 100 percent (from 12.8 to 22.3 mph), which is a significant improvement even if the speeds may not reach the minimum desirable for a strategic arterial. The study of community response to the implementation of access control yields much insight into and demonstrates the effectiveness of a well-planned and well-executed public information program.

CHAPTER 5. GEOMETRIC FEATURES

INTRODUCTION

The design of a strategic arterial represents a compromise between desirability and practicability. In practice this compromise is a trade-off between operational quality and feasibility of implementation. It is postulated that some reduction in operational quality and/or productivity is acceptable if this reduction significantly enhances the probability of implementation. Furthermore, since the implementation of a strategic arterial requires more resources than that of an ordinary arterial street, a strategic arterial should deliver significantly better traffic service than an ordinary arterial. Abstractly speaking, "a best buy" among competing systems composed of either freeways, strategic arterials, or ordinary arterials may be determined by estimating and comparing the cost-effectiveness of each class. However, the *feasibility* of implementing each of the various functional classes is not amenable to similar abstract quantifications in the sense that the "best buy" may not be available or may be available only after a very long (in human terms) gestation period. The feasibility of implementation, or *implementability*, is affected by political, social, and economic factors that are difficult to identify, much less quantify, and difficult to resolve. Feasibility is, however, *influenced* by cost-effectiveness analysis, which is a useful device for planning purposes but is not prescriptive. In order to be feasible, a project has to be both desirable and acceptable. The desirability of a proposed street facility is related to both its cost and its productivity (speed, quality of service, and capacity), whereas the acceptability is influenced by the interaction between the facility and its physical, social, and political environment. The geometric design of a strategic arterial is the determining factor, with respect to the quality of traffic service, and can have a significant effect on feasibility because there are acceptable trade-offs between geometric design and environmental concerns. This report primarily addresses the effect of design on service quality and productivity and it is presumed that the level of service proposed for strategic arterials, which is acknowledged to be less than that for a freeway, will permit design alternatives which improve feasibility.

The quality of service of a strategic arterial is a function of design. This quality is usually stipulated by assigning a design speed. As suggested before, the appropriate design speed for strategic arterials will be on the order of 50 mph or higher, with 40 mph a desirable minimum. The maximum design speed is more or less a function of the frequency of at-grade intersections modified by frequency of access and consideration for traffic safety. In planning strategic arterials, careful consideration should be given to selecting a minimum design speed for some *segments* of the system such that the *system* will deliver as promised. It is assumed that strategic arterial routes will incorporate routes from the existing and planned street and thoroughfare system. This implies that there will be segments on some of the existing routes within mature urban areas that support land use (such as traffic-dependent shopping and residential areas) which are accessed by frequently occurring driveways. Such land use makes it difficult to support the maximum design speed from the standpoint of safety and acceptability by abutting property interests who may even be hostile to having their street preempted as a strategic arterial. For maintaining route and system continuity it may be expedient to accept less than desirable design speeds for these segments. Such a decision is not to be taken lightly and should be accepted only if the alternative is worse. As will be discussed, there are design features which can be incorporated into a strategic arterial which can enhance the safe operating speed when access is difficult to manage.

In order to ensure compatibility of the geometric elements with the relatively high design speed on strategic arterials, keeping driver safety and driver guidance in mind, design guidelines need to address:

(1) horizontal alignment,
(2) vertical alignment,
(3) cross section elements (including clearances, lane widths, median treatment), and
(4) right-of-way requirements.

HORIZONTAL ALIGNMENT

AASHTO (Ref 18) provides detailed discussion on the relationships between design speed, superelevation, and horizontal curve radii. These concepts, as described by AASHTO, have been well established and are used in practice as the fundamental reference for designing roads. It is usual practice in planning and designing a new facility to select an alignment, including radii, that is commensurate with a desirable design speed, as controlled by, for example, location and the amount of right-of-way available or prescribed, and then to select the superelevation applicable to the curvature selected. In upgrading an existing facility to strategic arterial standards, a planner must weigh the utility and value of the salvageable elements of the existing facilities against the additional cost of reconstruction. AASHTO horizontal alignment criteria are derived primarily from such factors as expected running speed, pavement surface friction, and cross-slope. These criteria are not affected by environmental or operating conditions peculiar to an urban environment. AASHTO's policy on horizontal alignment is considered to be sufficient as a guideline for designing strategic arterial streets.

SIGHT DISTANCE AND VERTICAL CURVATURE

Stopping Sight Distance

Sight distance influences geometric design and consequently the feasibility of implementation. Increasing sight distance may also increase construction costs. These effects are particularly true with respect to the design of grade separations and interchanges. The length of a grade separation facility is to a degree (depending upon the terrain, clearances, and structure characteristics) a function of sight distance. This can be important in *adapting* a grade separation facility to fit into and serve abutting boundaries. In turn, the length of the grade separation facility will affect the length of entrance and exit ramps at interchanges. Ramp lengths also affect adaptability as well as traffic-weaving distances between successive entrance and exit ramps. The more adaptable the facility is, the easier it is to fit into and provide access, without disruption, to the existing street patterns of an urban environment. Construction costs may also be affected by sight distance since increasing the sight distance may also increase costs.

There is also the special case of preempting and adapting existing facilities as strategic arterials. It is quite possible that older, but still serviceable facilities, which were designed and constructed when sight distance standards were less restrictive, may not meet more recent criteria. The expensive, disruptive, and time-consuming solution to this problem is to reconstruct the deficient facilities. An alternative would be to consider a speed limit reduction through the area where the sight distance is considered impaired. Another alternative would be to reexamine the sight distance criteria and see whether or not there are rational and plausible reasons for justifying the use of the existing facilities.

Based on available research results, AASHTO (Ref 18) provides friction factors which can be used by designers to calculate safe stopping distances. AASHTO also recommends the use of a brake reaction time of 2.5 seconds, which is the interval between the instant that the driver perceives the existence of a hazard in the roadway ahead and the instant that the driver applies the brakes. This value of brake reaction time recommended by AASHTO is considered conservative, especially when applied to urban driving conditions, where the presence and reactions of other vehicles in the traffic stream should stimulate driver alertness and provide additional forewarning of roadway hazards.

Reaction time to an expected event has been estimated to have a value of between 0.4 and 1.7 seconds, with a median of approximately 0.66 second; approximately 10 percent of test subjects require 1.5 seconds or longer. Unexpected signals require an *additional* 1 to 1.5 seconds. Drivers on strategic arterials are required to make decisions frequently; therefore, they operate in an alerted condition as they respond to the everchanging environment. It is thus suggested that in designing strategic arterials, consideration be given to using a *representative* reaction time for alerted drivers to calculate sight distances.

Other cases may allow a less conservative approach. An example is sight distance over crest vertical curves. The approach to the design of vertical curves is already fairly conservative and the use of a shorter reaction time in the determination of required sight distance in these cases may be appropriate.

For comparison, Table 5.1 shows stopping sight distances required for a range of design speeds (again the range of design speeds applicable to strategic arterials is 45 to 55 mph), with sight

Table 5.1 Required stopping distances for selected design speeds and reaction times of 1.5 and 2.5 seconds

		Brake Reaction				Stopping Sight Distance (2.5-sec reaction time)	
Design Speed (mph)	Assumed Speed for Condition (mph)	Time (sec)	Distance (ft)	Coefficient of Friction f	Braking Distance (ft)	Computed (ft)	Rounded (ft)
35	32 - 35	2.5	117.3 - 128.3	0.34	100.4 - 120.1	217.7 - 248.4	225 - 250
40	36 - 40	2.5	132.0 - 146.7	0.32	135.0 - 166.7	267.0 - 313.3	275 - 325
45	40 - 45	2.5	146.7 - 165.0	0.31	172.0 - 217.7	318.7 - 382.7	325 - 400
50	44 - 50	2.5	161.3 - 183.3	0.30	215.1 - 277.8	376.4 - 461.1	400 - 475
55	48 - 55	2.5	176.0 - 201.7	0.30	256.0 - 336.1	432.0 - 537.8	450 - 550
60	52 - 60	2.5	190.7 - 220.0	0.29	310.8 - 413.8	501.5 - 633.8	525 - 650

		Brake Reaction				Stopping Sight Distance (1.5-sec reaction time)	
Design Speed (mph)	Assumed Speed for Condition (mph)	Time (sec)	Distance (ft))	Coefficient of Friction f	Braking Distance (ft)	Computed (ft)	Rounded (ft)
35	32 - 35	1.5	70.4 - 77.0	0.34	100.4 - 120.1	170.8 - 197.1	175 - 200
40	36 - 40	1.5	79.2 - 88.0	0.32	135.0 - 166.7	214.2 - 254.7	225 - 275
45	40 - 45	1.5	88.0 - 99.0	.0.31	172.0 - 217.7	260.0 - 316.7	275 - 325
50	44 - 50	1.5	96.8 - 110.0	0.30	215.1 - 277.8	311.9 - 387.8	325 - 400
55	48 - 55	1.5	105.6 - 121.0	0.30	256.0 - 336.1	361.6 - 457.1	375 - 475
60	52 - 60	1.5	114.4 - 132.0	0.29	310.8 - 413.8	425.2 - 545.8	450 - 550

distances which include both 2.5- and 1.5-second reaction times. An existing facility considered for upgrading to strategic arterial status should also be evaluated in terms of suitability to the appropriate design speed in terms of sight distances past obstructions, around horizontal curves, and at vertical curves.

Vertical Curvature

Curve lengths determined by required sight distance are generally satisfying from the viewpoints of safety, comfort, and appearance. In the case of new facilities, the sight distances must obviously be compatible with the design speed. Table 5.2 gives the appropriate K-values for crest vertical curves based on the stopping sight distances given in Table 5.1 and the assumptions discussed above.

Very flat vertical curves may cause a drainage problem, especially on curbed sections. A minimum grade of 0.3 percent or steeper, within 50 feet of a level point, is considered adequate. This curve represents a K-value of 167 or larger (Ref 18).

Various criteria determine the required length of sag vertical curves. The most important are headlight sight distance, rider comfort, drainage control, and sight distance underneath structures. Headlight sight distance is usually the most critical, bounded by the consideration of drainage, mentioned above. A case could be made that the headlight sight distance is not required on lighted facilities, in which case the comfort criterion becomes critical. AASHTO (Ref 18) suggests the following as a comfort criterion:

$$K = V^2/46.5 \qquad (5.1)$$

where V is the design speed in mph. Equation 5.1 is based on approximating a sag vertical curve with a circular curve and allowing a centripetal acceleration of 1 ft/s^2.

Table 5.3 shows the K-values—for a range of design speeds—that are required both in cases when sight distance governs and when the comfort criterion governs (such as in a lighted facility).

A good case can be made for the need to illuminate strategic arterials. The need is based on the relatively high speed assumed for a basically urban facility and takes into account driver safety and comfort. The presence of street lighting also reduces the required minimum K-values for vertical curves and consequently their length. This is significant when considering grade separations, where the total length of elevated or depressed roadway can be critical, as discussed in Chapter 6.

The formula for calculating sight distance over a vertical crest curve is very sensitive to the height-of-eye and the height-of-object relationship set out

Table 5.2 **K-values for crest vertical curves for range of design speeds and brake reaction time of 2.5 and 1.5 seconds**

Design Speed (mph)	Assumed Speed for Condition (mph)	Coefficient of Friction f	Based on 2.5-sec Brake Reaction Time			Based on 1.5-sec Brake Reaction Time		
			Stopping Sight Distance, Rounded (ft)	Rate of Vertical Curvature (K)		Stopping Sight Distance, Rounded (ft)	Rate of Vertical Curvature (K)	
				Calculated	Rounded		Calculated	Rounded
35	32 - 35	0.34	225 - 250	35.7 - 46.4	40 - 50	175 - 200	21.9 - 29.2	30 - 30
40	36 - 40	0.32	275 - 325	53.6 - 73.9	60 - 80	225 - 275	34.5 - 48.8	40 - 50
45	40 - 45	0.31	325 - 400	76.4 - 110.2	80 - 120	275 - 325	50.9 - 75.5	60 - 80
50	44 - 50	0.30	400 - 475	106.6 - 160.0	110 - 160	325 - 400	73.2 - 113.1	80 - 120
55	48 - 55	0.30	450 - 550	140.4 - 217.6	150 - 220	375 - 475	98.4 - 157.2	100 - 160
60	52 - 60	0.29	525 - 650	189.2 - 302.2	190 - 310	450 - 550	136.0 - 224.1	140 - 230

Table 5.3 **K-values for sag vertical curves for range of design speeds and where headlight sight distance or comfort criterion rules**

Design Speed (mph)	Assumed Speed for Condition (mph)	Coefficient of Friction f	Based on Headlight Stopping Sight Distance with 2.5-sec Brake Reaction Time			Based on Comfort Criterion Only	
			Stopping Sight Distance, Rounded (ft)	Rate of Vertical Curvature (K)		Rate of Vertical Curvature (K)	
				Calculated	Rounded	Calculated	Rounded
35	32 - 35	0.34	225 - 250	40.8 - 48.6	50 - 50	22.0 - 26.3	30 - 30
40	36 - 40	0.32	275 - 325	53.4 - 65.6	60 - 70	27.9 - 34.4	30 - 40
45	40 - 45	0.31	325 - 400	67.0 - 84.2	70 - 90	34.4 - 43.5	40 - 50
50	44 - 50	0.30	400 - 475	82.5 - 105.6	90 - 110	41.6 - 53.8	50 - 60
55	48 - 55	0.30	450 - 550	97.6 - 126.7	100 - 130	49.5 - 65.1	50 - 70
60	52 - 60	0.29	525 - 650	116.7 - 153.4	120 - 160	58.2 - 77.4	60 - 80

by AASHTO policy. The height-of-object is set at 6 inches according to the 1990 AASHTO *Policy on Geometric Design of Rural Highways* (Ref 18). This object height criterion has evolved over the years and represents a compromise between the height of a hazardous object to be avoided and a dimension to be used in the sight distance formula that does not result in an overly long vertical curve. In a queuing traffic flow situation, such as expected on a strategic arterial, a driver is not likely to see or even be looking for a 6-inch object. More likely, attention is directed to the brake lights of the vehicle in front, which are more on the order of 24 inches in height. Newer passenger cars are required to have a supplemental brake light that is mounted even higher. The point is that minimum sight distance standards have not necessarily been derived from analysis of traffic operations and safety; therefore, these standards may warrant specific scrutiny as they relate to the design of strategic arterials. Sight distance under structures at the gradients, vertical curves, and vertical clearances associated with the type of facility under consideration here are usually not critical, but they need to be checked nevertheless.

Vertical Gradient

Critical grades combined with the length of gradient are based on the reduction in speed which heavy vehicles undergo while climbing an upgrade. Most research in this respect has been performed on rural roads, but ranges of available results are adequate to cover arterial streets and, in this case, strategic arterials as well. The critical length of grade is then defined as the length of an ascending grade on which a loaded truck can operate without an "unreasonable" reduction in speed (Refs 18 and 61). It is suggested that consideration be given to assuming an allowable speed reduction of 10 mph below the average running speed of traffic on strategic arterials. A value of 15 mph is suggested for all urban streets (Ref 60). These speeds are consistent with speed differential values suggested elsewhere in this report. AASHTO (Ref 18) offers curves showing the deceleration of heavy vehicles on grades to assist in this process.

Critical grades should not be an issue in most Texas cities because the terrain is such that long steep gradients are not likely to be encountered. More likely, gradients are established to provide clearances over and under other roads, streets, and railroads. The usual case in establishing minimum length clearance profiles in urban areas is for succeeding crest and/or sag vertical curves to join or be separated by a short length of tangent grade. These gradients are usually relatively short and the maximum uniform grade would not be sustained for more than 100 or 200 feet. Consequently, sustained steep grades are not a problem nor are the speed reduction effects of steep gradients. A long, sustained grade of 5 or 6 percent might not be acceptable in a rural environment, whereas a short tangent grade of 7 to 9 percent might have little effect on traffic operations in an urban area.

It is desirable to reduce the grade through intersections on roadway sections with moderate to steep grades. A value of 2 percent maximum, for 100 to 300 feet, is desirable to facilitate turning and stopping (Ref 61).

CROSS-SECTION ELEMENTS

Lateral Clearance

Lateral clearances affect capacity to a certain extent, and should be considered when selecting (1) lane widths, (2) shoulder widths, and (3) placement of cross-section elements (including median barriers and curbs), retaining walls, and overcrossing structure supports. It follows, however, that under urban traffic operating conditions, the extreme lateral clearance requirements established as safety measures in rural areas may not be warranted in an urban traffic environment. Within the urban environment, a driver is continually confronted with overhead utility poles and guy wires planted adjacent to curb lines, parked cars, bicyclists, and pedestrians, not to mention opposing traffic on two-way streets. Fortunately, travel speeds are much lower in an urban environment and drivers are continually alert to the expected hazards and are able to tolerate driving conditions that would not be acceptable in a rural environment. Furthermore, the average urban trip distance is much shorter than one on the rural highway system, so that the physical demands on driver alertness and reactions are of much shorter duration. Consequently, providing excessive lateral clearances with respect to abutting structures along arterial streets is not likely to have a perceptible effect on overall driver safety. In fact, a reasonably well-designed arterial street should provide safer passage than any other urban road or street facility, except a freeway.

Both the Highway Capacity Manual (Ref 16) and AASHTO (Ref 18) address the issue of lateral clearances and recommend clearance dimensions which permit a measure of discretion by the designer. The most significant effect of lateral clearances on strategic arterials will be on structure span lengths in grade separations. The more lateral clearance that is required, the longer the overcrossing structure span that is required. This in turn may increase the depth of the overcrossing superstructure and hence the profile clearance interval between grade-separated roadways. Longer spans adversely affect both construction costs and adaptability.

Vertical Clearance

Both AASHTO and the SDHPT recommend a minimum vertical clearance of 16 feet plus 0.5 foot for future pavement overlay and/or snow accumulation for most highway systems. The SDHPT standards will permit a minimum vertical clearance in urban areas of 14 feet plus 0.5 foot and will permit the retention of existing structures on the highway system if a 14-foot clearance is available. Most cities use as a standard the lower of the AASHTO and SDHPT allowable clearances of 14.5 feet.

AASHTO recognizes a class of highways called parkways, which are reserved for passenger vehicles only. Under these conditions, AASHTO permits a minimum vertical clearance of 12.5 feet, as opposed to 15 feet, as desirable.

It is suggested that strategic arterial streets should provide for a variety of clearances depending upon potential conflicts with truck traffic. If a strategic arterial is part of the state highway system, then a minimum clearance of 16.5 feet should be provided along the route. For strategic arterials serving predominantly intra-urban trips, the 14.5-foot clearance should be adequate and is consistent with that allowed by the cities and counties.

Median Treatments

In this section, several types of median treatments applicable to the design of strategic arterials are discussed. The installation of a continuous median barrier on strategic arterials enhances safety and improves traffic operations. The barrier is particularly effective where right-of-way is constricted and the space provided for the median is narrow. The barrier is also useful for inhibiting left-turn crossover movements in mid-block areas. What might be considered illegal without a barrier becomes virtually impossible with the barrier in place.

Design of Urban Streets (Ref 60) offers a general classification and overview of median barriers. Medians on urban streets are either a physical barrier or a painted (delineated) barrier. Medians are installed to satisfy one or more of the following purposes: to control or protect crossover or other turning movements, to provide pedestrian refuge, to provide an area for landscaping, and to separate opposing traffic. A secondary purpose in selecting a barrier type, of special interest for strategic arterials, is the conveyance of a visual cue to drivers who are either using or approaching the facility, as to the type of facility they are or will be using and what type of operational controls they can expect. An example of this application is sections of US Routes 1 and 130 in New Jersey, which were described previously.

Physical medians can be classified into three configurations:

(1) narrow-barrier medians, from 4 to 8 feet wide, used to prohibit left turns and crossovers;
(2) medians with turn bays, from 12 to 20 feet wide, used to provide exclusive left-turn lanes at specific intersections and driveways; and
(3) wide medians, with a minimum width of 24 feet, used to protect vehicles crossing the arterial and provide the opportunity for double left turns at major intersections.

Painted medians can also be classified into three configurations (Ref 60):

(1) those at intersections only, where a restriction on crossing in mid-block is in force;
(2) those forming left-turn bays along a section of arterial, allowing left turns into specific driveways and cross streets; and
(3) continuous two-way left-turn medians, along which vehicles may turn left from either direction along the length of the arterial section.

There are a few general criteria that may be useful for selecting a median barrier:

(1) Installation cost.
(2) Maintenance cost and effort. In addition to the the cost of actual repair, the barrier's resistance to major damage and the extent of the damage incurred from a standard crash load should be considered. User's cost because of "down-time" while the barrier is being repaired is an important consideration. User's cost is also related to the frequency of repair work (which is linked to the durability of the barrier) and the exposure of barrier maintenance crews to the hazards of traffic (Refs 62 and 63).
(3) Safety, considering the relatively high speeds envisaged for strategic arterials. To be considered is the efficiency of the median treatment in redirecting stray vehicles, as protection against head-on collisions, and in controlling the scale of any mishap, e.g., the consequences of a vehicle impacting against a barrier.
(4) The efficiency of the median barrier to partly control access, by discouraging and prohibiting mid-block left turns.
(5) The effect of the barrier in communicating to road users the nature of the particular facility, as mentioned above.

Median treatment as discussed herein is directed toward the efficient utilization of right-of-way, or to put it another way, toward getting the most productivity out of a given width of right-of-way. It is presumed that acquiring rights-of-way will always be difficult and expensive and that it is easier to obtain a lesser rather than a wider width of right-of-way. Of course, this assumption does not always apply, for example, where the cost of partial takings resulting from the remaining damages may be just as expensive as whole parcel takings. There is also the possibility of acquiring rights-of-way in areas where land is relatively inexpensive, even in urban areas, and where additional right-of-way can be acquired without having a significant effect on the displacement of people and businesses. Without exception, the design of a strategic arterial can always be improved by the availability of additional rights-of-way. Right-of-way can be converted into additional traffic lanes in one extreme or used as park area in the other extreme or both if there is sufficient room. However, for the purposes of this study it is assumed that rights-of-way are restricted, and the first priority is to maximize arterial street productivity. The need for additional rights-of-way for environmental improvement is difficult to quantify, considering the present state of the art in traffic engineering. Even though most planners agree that dedicating additional resources for environmental enhancement is important and valuable, an action to do so is basically a political decision and beyond the scope of this report. Consequently, in addressing guidelines, this report evaluates median barriers as if conserving rights-of-way is an important consideration.

Curbed Medians

Curbed medians can be almost as effective in controlling crossover movements as any of the more formidable barriers, but they do not offer the protection against head-on collisions or guidance of an out-of-control vehicle that concrete or steel barriers do. Curbs provide no safety benefits on high-speed roadways from the standpoint of vehicle behavior following impact. Although curbs improve delineation and improve drainage, they have little effect in redirecting errant vehicles and should not be used for that purpose (Ref 63). Advantages of curbed medians include relatively low installation and maintenance costs. Curbed barriers are considered by some to be more aesthetically pleasing than the other types of physical barriers mentioned. This point is often emphasized when the arterial passes through or in the vicinity of suburban residential areas. Curbed medians do not offer any protection from the headlight glare from oncoming vehicles. Headlight glare screens are relatively expensive and require regular and often costly maintenance. Minimum recommended width for a curbed median is 4 feet, and 8 feet is a desirable minimum. At intersections only, where curbed medians are used to outline left-turn lanes and separate oncoming traffic, an 18-inch-wide median is considered to be satisfactory. Curb shapes vary greatly. The usual height considered effective as a barrier curb is 6 inches, with a face slope of 6 inches vertical to 1 or 2 inches horizontal.

Concrete Median Barriers

The most widely used concrete median barrier is the New Jersey shape barrier. As indicated by its wide application on freeways, both as permanent features and as temporary barriers used during construction, there is little doubt as to the applicability of concrete median barriers to facilities where high speeds prevail. A continuous concrete median barrier obviously offers excellent control in preventing crossover movements and as protection against head-on collisions. Much research has been done on vehicles impacting with the New Jersey type barrier, and results emphasize its capacity to minimize accident severity. Research results, however, indicate that use of the system should be restricted to locations where the probable impact angle is less than 15 degrees, for vehicle occupants' safety (Ref 64). The 15-degree restriction is not likely to be a factor where strategic arterials are concerned, since these barriers are considered satisfactory for freeways with narrow medians.

The New Jersey barrier was actually developed by the NJDOT for use in retrofitting existing urban highway routes, rather than for freeway conditions (see Chapter 4). The original barrier was 16 inches high and it was subsequently raised to 20 inches and then to the present 32 inches.

As these types of barriers are not very often used on urban streets, use of a continuous concrete median barrier lends itself very well to the concept of communicating to drivers the extraordinary nature of high mobility arterials. Although the concrete median barrier is a formidable barrier to crossing, it may not be aesthetically pleasing. This may count against the use of this type of barrier in some suburban areas because of possible negative community response.

Compared with other types of median treatments, installation of concrete barriers is relatively expensive, but maintenance, even if the barriers are impacted by vehicles, is relatively low. Concrete median barriers also offer some protection against headlight glare.

Pedestrians have been known to cross heavily trafficked streets and climb, or attempt to climb, over concrete median barriers. Such behavior is illegal, and, in addition, the sight of a pedestrian astride the median barrier searching for the pavement surface may provoke erratic driving behavior and thereby cause an collision. The pedestrian is generally the ultimate loser in such a situation, but it is not clear how such irrational or adventurous acts can be averted. It is doubtful that continuous median barriers should be considered a hazard to pedestrians.

Metal Beam Guard Fences

Many types of metal guard fences are available and in use. The most common type consists of a W-beam mounted on steel or wooden posts. A "blocked-out" version is also used, in which the steel beam is offset horizontally from the posts in order to minimize the potential for a vehicle snagging on the posts and to reduce the tendency for a vehicle to vault over the rail. These types of barriers can also be installed within a curbed median. Curbs are not effective in redirecting an impacting vehicle at high speed (50 mph or higher), but a low curb (4 in. or less) backed up by a barrier can be effective in redirecting slower (less than 40 mph) impacting vehicles. The curb-barrier installation is no longer recommended for freeways because of the "tripping" action if the barrier is offset more than a few inches behind the curb. However, the average running speeds along strategic arterials are significantly lower than those for freeways, and objections to this type of installation should be less frequent. The curbed median provides a high degree of delineation, which is useful for channeling traffic, particularly during darkness and inclement weather. Another advantage is the ease with which a curbed median can be changed into a curb-barrier type median. This transition is useful where and when higher operating speeds mandate the installation of a barrier between opposing traffic streams. As discussed previously, the barrier may also discourage pedestrians from crossing. Data supplied by the Texas State Department of Highways and Public Transportation indicate that installation costs of metal beam guard fences are about the same as those of the concrete median barrier. Metal beam guard fences require higher levels of maintenance than do concrete median barriers because damage to the guard fence, in cases of impact, is usually more severe.

Some consider the metal beam guard fence to be aesthetically more acceptable than concrete median barriers, particularly for application within suburban areas. When used as a continuous barrier, the guard fence is effective in communicating the nature of strategic arterials to drivers.

Table 5.4 summarizes the relative adaptability of the different types of median treatments. This adaptability was considered with respect to its applicability to *strategic arterial streets.* AASHTO (Ref 63) offers details on barrier design and performance.

In summary, the use of a physical median barrier on strategic arterials is essential unless a very wide (40 feet or wider) median is present. The use of a continuous concrete median barrier is strongly recommended. In locations where aesthetic considerations are of importance, the metal beam guard fence may be considered an acceptable alternative. Treatment of sections on curves and end-treatment of barriers at, for example, intersections also need specific attention.

Painted Medians

Painted medians of any type have severe limitations as far as their applicability to strategic arterials. In practice they will have little effect on controlling undesired access and turning movements. Even where crossing movements are prohibited by demarcation and signing, painted medians will probably be ineffective unless the prohibitions are continuously enforced. Non-adherence to the regulations by drivers will lead to the same, if not worse, negative effect on through-traffic. Further, painted medians do not offer protection against head-on collisions, should a vehicle stray into oncoming lanes, and such protection is very desirable, especially on facilities with higher design and operating speeds.

Although two-way left turns are often used on collector and arterial streets, the reasons for not providing painted medians generally will also apply to two-way left-turn lanes. Two-way left-turn lanes have the further disadvantage that they not only physically (and through regulation) allow mid-block left turns but that by their very nature they invite such turns. Continuous two-way left turns are usually installed where there is a specific need for property access from both directions and in order to remove some of the problems encountered with left turns at such locations. A further very important aspect is that the type of traffic operations associated with two-way left turns (such as slow-moving vehicles in the left-hand lane, a certain amount of driver uncertainty, and vehicles crossing oncoming traffic lanes at undetermined locations) will be incompatible with the higher operating speeds envisaged and desired on strategic arterials.

Table 5.4 Performance of median treatments on criteria for strategic arterials

	Criteria					
Median Type	**Controlling Mid-block Crossovers**	**Relative Installation Cost**	**Relative Maintenance Cost and Effort**	**Offering Cues on Nature of Arterial**	**Aesthetics**	**Protection w.r.t. Errant Vehicles**
Concrete median barrier	Excellent	High	Low	Excellent	Poor	Excellent
Metal beam guard fence	Excellent	High	High	Good	Moderate	Good
Curbed median	Good	Moderate	Low	Poor	Good	Poor
Painted median	Very poor	Low	Moderate	Very poor	Good	Very poor

Lane Widths

Lane widths on typical urban streets vary from 9 to 12 feet, with 11 feet an approximate norm. On facilities where speeds in excess of 40 mph occur, such as on the proposed strategic arterials, 12-foot lane widths are desirable. While substantial traffic volumes can be accommodated in reduced lane widths and lanes of 9 feet can be used (where the alternative is less desirable), this is not recommended. If narrower lanes are used the adverse effect of larger vehicles on general traffic operations will become more pronounced, resulting, for example, in increased driver tension and wider speed and headway distributions (Refs 60 and 61). The 1985 Highway Capacity Manual (Ref 16) estimates a 10 percent increase in capacity from increasing a lane of 12 feet to 15 feet, and a 10 percent increase in capacity from increasing a lane of 9 feet to 12 feet. The justification for wider versus narrower lanes should be a function of the amount of truck traffic and the amount of curvature present. Increases in both truck traffic and curvature warrant the use of wider lanes in order to improve operational stability and maximize productivity.

Very wide lanes and large undelineated pavement areas can lead to driver uncertainty and even conflicts where turning movements take place. A lane width of 16 feet is the maximum recommended if drivers are expected to operate in single file (Ref 60). It has been observed that barrier curbs act as a lateral obstruction in that drivers tend to place their vehicles 12 to 18 inches further from a barrier curb than from other less imposing border treatments. Where barrier curbs are used, an increase of one foot in the width of the rightmost lane is recommended (Ref 60).

SHOULDERS OR AUXILIARY LANES

There are significant advantages in providing a shoulder or auxiliary lane along strategic arterial streets. The overall advantage is that a shoulder or auxiliary lane will contribute to the reliability of operations by providing the motorist with some operating space not ordinarily available along most arterial streets. Specific advantages (Refs 18, 47, and 60) are:

(1) emergency stopping, without hazard to and from or interference with through-traffic, provided the shoulder is wide enough;
(2) space for speed changes when entering or exiting driveways;
(3) use as a right-turning lane at approaches to intersection;
(4) lateral clearance to roadside objects is increased, and capacity increases, uniform speeds and headways are encouraged, and a contribution is made to ease of driving and reduction of driver stress;
(5) less traffic impedence from flooded gutters during heavy rains;
(6) space for police to enforce traffic regulations; and
(7) space for detours during maintenance operations.

To allow a passenger car to stop clear of the active roadway, a shoulder at least 10 feet wide is required, considering the vehicle width of approximately 6 feet, clearance to the curb or border of 1 or 2 feet, and minimum space to open a door. If heavy vehicles are to be catered to, the required width increases to 12 feet or more. If the area is also to be used as a continuous right-turn lane, a lane of at least 11 feet, and preferably 12 feet, is recommended. A case can always be made that, in very restricted areas, even a very narrow shoulder (one of only a few feet) is better than no shoulder at all.

Curbs

Curbs on the roadway edge control drainage, delineate the roadway edge, deter vehicles from leaving the paved surface, and aid in channelizing vehicle movements. Curbs provide some protection for pedestrians, permit the control of access to designated driveway locations and assist in orderly roadside development, provide lateral support to the roadway or shoulder pavement, reduce maintenance work, and present a more aesthetic appearance (Refs 18 and 61). Curb cross sections may vary a great deal but the usual configuration is 6 inches high with a front slope of six vertical to 1 or 2 inches horizontal. This arrangement provides the approximate combination of delineation and deterrence without being a hazard to encroachments at moderate speeds.

U-TURNS AND INDIRECT LEFT TURNS

The provision of indirect left turns as an alternative to providing protected direct left turns at traffic signals is discussed below. Enforcement of left-turn restrictions by the use of continuous median barriers will require provisions for U-turns at appropriate spacings. The dimensions needed to provide for U-turns within an adequate median width are such that additional rights-of-way will be necessary. An AASHTO report on highway and street design (Ref 18) showed that a 70-foot-wide median would be required to provide for a U-turn from left lane to left lane for the WB-50 design vehicle, and that a 30-foot-wide median would be required for passenger cars. Where encroachment on the lanes in the opposite direction is allowable, and the roadway is 24 feet wide, the above values reduce to 52 feet and 20 feet for the WB-50 design vehicle and the passenger car, respectively. U-turn provision can be made through jug-handle configurations, which require only local widening of the right-of-way. Design guidelines, based on those of the New Jersey Department of Transportation, for U-turns and indirect left turns are shown in Figures 4a, 4b, and 4c.

PAVEMENT QUALITY AND DESIGN

Pavement quality has a direct effect on safety and driver comfort, which can affect desired speed and desired speed differential, causing overall lower travel speeds. Safety aspects are mostly related to the need to provide adequate skid resistance. Although most dry surfaces provide adequate skid resistance, wet pavements showing some deterioration may not. Rutting in wheel tracks causes water accumulation on the surface, and polishing and bleeding of the pavement surface also reduce skid resistance, increasingly so when the surface is wet (Ref 18).

Pavements that are smooth and have a proper cross slope allow drivers to steer easily and on a proper path. The perception of high-quality pavement by motorists should heighten their expectancy of an overall high-quality facility. The principle on which most pavement design guides are based is that the pavement should retain its shape and quality and support the projected volume and weight of vehicles without showing fatigue. Loss in serviceability causes drivers to slow and, thus, average travel speeds to decrease (Ref 65). Very few studies have been done to correlate pavement quality with driver behavior.

Pavement quality also includes durability. A strategic arterial street is expected to be used to its tolerable capacity. Under these conditions, reliability of operations is very much affected by accumulated water in ruts and irregular surfaces and by "down-time" caused by maintenance operations. These inhibitions to reliable operations are very much a by-product of pavement quality. Maintenance activities, whether planned or non-routine, have a major effect on traffic operations, which is the reason that freeway maintenance is usually the subject of rigorous planning. While high-quality pavements require less non-routine maintenance, it is also very necessary to take the effect of traffic disruption into account when making an economic evaluation to decide on the quality of pavement to be provided and when planning for rehabilitation (Ref 65). Considering the envisaged role of strategic arterials in the urban road network, the evaluation of the effect of planned rehabilitation and reconstruction should also include the effect on other facilities. Economic evaluation over longer periods, which includes the capital outlay and user cost of one or more cycles of rehabilitation or reconstruction, tends to favor installing higher-quality pavements initially. Because strategic arterials are classified as high-volume urban roads, economic evaluation should be performed for a period of 30 to 50 years, as recommended by AASHTO (Ref 65).

Since the role of the strategic arterial within the urban road networks is to provide high-quality traffic service, if follows that maintenance and repair activities on strategic arterials should be given the same attention as is given to these activities on freeways. Maintenance operations should be undertaken during periods of reduced traffic demand. Traffic handling during maintenance operations should provide additional driver assistance and driver directions, including provision of alternative routes. Not specifically addressed here, but also relevant, is the provision of proper drainage of the roadway to limit the probability that rainwater accumulation will unduly inhibit traffic operations.

SIGNING

Although signing on freeways is characterized by high quality, consistent application, and the frequent use of diagrammatic information, the signing on arterial streets is subject to wide variations. With the use of grade-separated interchanges and U-turn and indirect left-turn provisions, and to ensure high levels of consistency and driver guidance, high-quality signing will be required. This quality of signing is especially important because some of the elements of strategic arterials covered in this study—grade-separated intersections, for example—are not standard for urban arterials. Two applications discussed above, namely the use of indirect left turns and partial control of access by median treatment in New Jersey and on Route US 67 in St. Louis, offer examples of applying specific standards of signing.

The *Manual on Uniform Traffic Control Devices* (MUTCD) (Ref 67) recommends sizes of signs and lettering be used that are commensurate with the class of highway. Viewing its classification with respect to freeways and other arterials, it seems the use of standards of signing recommended for use on expressways will be most suitable for strategic arterials. Some reduction of standards will be necessary (e.g., the recommended advance sign placement because of shorter intersection spacing), but it is recommended that major exits from the strategic arterial (e.g., at grade-separated intersections and at U-turn and indirect left-turn facilities) be treated similarly to lesser type interchanges. Standards of signing recommended by the MUTCD for Interchange Type 1(b) on expressways (i.e., intersection of an expressway with a principal urban arterial) seem the most appropriate.

UTILITIES

It is generally recognized that urban street right-of-way, apart from serving vehicular traffic, also provides space for public utilities. Some of these utilities may be there to support the traffic-carrying role of the street, such as lighting or signal cables, or for drainage. Many others primarily serve surrounding developments and include water supply lines, power and communication lines, oil and gas pipelines, and sanitary sewers. The presence of utilities affects road design and construction activities, through considerations such as the cost and effort involved in relocating utilities, the appearance of the roadway, maintenance efficiency, and traffic safety. These considerations also affect strategic arterials, and reference has been made to required lateral clearances, but of special importance is the effect of utility installation and maintenance on traffic operations. While the placement of utilities on freeway right-of-way is very limited and subject to very strict guidelines, the same does not apply to urban streets (Refs 18, 68, and 69).

Guidelines applicable to urban streets, which should also apply to strategic arterials, include the provision that sidewalk and median space, rather than traffic lanes, be reserved for the placement of underground utilities (Ref 61). The reservation of right-of-way space for placement of utilities on urban streets is contradictory to one of the aims for strategic arterials. It should be emphasized that the best utilization of available rights-of-way is to enhance traffic mobility.

It is suggested that some of the guidelines applicable to freeways should also be applied to strategic arterials: these guidelines should include efforts to restrict the placement of new utilities on strategic arterials to those which must be placed there to serve the specific facility or for which no other alternative is available, unless adequate right-of-way is available for utility work to be carried out without inhibiting traffic flow. The use of sidewalk space and the shoulder or continuous speed-change lanes is strongly preferred over the use of space under traffic lanes for the placement of underground utilities. Even work outside the traffic lane can be disruptive and unsafe because of spectator interest and the presence of work teams and equipment close to a high-speed facility.

As indicated, it is most likely that strategic arterials will be developed along existing arterials, where utilities are already in place and may be under road surfaces. In those cases it is recommended that consideration be given to the relocation of utilities while any reconstruction takes place. Routine and non-emergency work on utilities which causes traffic disruption should be carefully pre-planned, as it is for pavement maintenance activities, to minimize reduction in the arterial's role of providing reliable mobility.

ONE-WAY STREETS

Either converting existing streets to one-way couples or using existing one-way streets as sections of strategic arterials has very distinct advantages. The primary advantage in using one-way streets is the remoweal of the conflict between left-turning vehicles and opposing traffic, both at street intersections and at driveways. More space for through lanes may become available as the need to provide left-turn lanes is removed. Green-time for through traffic at traffic signals can be increased as phases for left-turns become unnecessary. Medial friction in the traffic stream is effectively removed and the overall effect of marginal friction is reduced by having more lanes per direction and some lanes not subject to marginal friction.

The American Society of Civil Engineers (ASCE) Committee on Urban Arterial Systems (Ref 70) offers a comprehensive list of the advantages, disadvantages, and indications for implementing one-way streets. Many of these are directly applicable to strategic arterials, as well as to any principal arterial, and are used as a basis for the following discussion.

Advantages

Most of the advantages of one-way streets are directly related to the reduction of conflicting movements, as mentioned above. The additional capacity, signal timing efficiency, and conflict reductions result in reduced travel time and delays. One-way operations remove the need for two-way progression of traffic signals and it is possible to obtain a continuous green band of consistent slope at any chosen speed through signals along extended arterial lengths. Capacity increases of up to 50 percent, travel time reductions of 20 to 40 percent, and stopped time reductions of 60 to 85 percent have been reported (Ref 70).

Accident reductions by as much as 50 to 60 percent have been reported. Accident types which are reduced are typically rear-end, sideswipe, head-on, turning, parking, and pedestrian-related. Mid-block accident reduction may be especially significant (Ref 70).

Disadvantages

The implementation of one-way streets may increase traffic circulation in the area and increase travel distances. Pedestrian crossing times will increase as the provision of refuge will not be viable.

Some businesses, especially those that rely on passing traffic, may be affected by one-way operations. This effect applies to any arterial street where access limitations are implemented, and is discussed further in Chapter 7.

ASCE's committee on Urban Arterial Systems (Ref 70), however, reports that, although initial opposition from business establishments is often encountered, such opposition often disappears after implementation, as one-way operations usually result in congestion relief, greater safety, and even increased property values.

Some Guidelines for Planning of One-Way Streets

(1) One-way pairs should be spaced close to each other, preferably not more than two street blocks apart.

(2) The two directions served should serve approximately the same origin and destination, and sequencing should follow the rule of the road, i.e., traffic in the opposing direction, even if spatially removed, should be on the left-hand side.

(3) Adequate provision for the circulation of traffic in the area and access to affected properties need to be considered, including the provision of adequate cross streets.

(4) As with the implementation of median barriers, access needs and the effect on properties in the area should be carefully considered.

(5) The needs of emergency vehicles require consideration.

CHAPTER 6. INTERSECTIONS AND GRADE SEPARATIONS

CONCEPTUAL MODEL

The planning and design of at-grade intersection traffic controls along strategic arterials should be directed toward achieving a target average travel speed along the length of the arterial. The average travel speed along a particular length of an arterial is largely a function of total intersection delay. Total delay is a function of the number of intersections involved and the delay incurred at each intersection.

A strategic arterial, by definition, should provide higher-quality traffic service than all other classes of roads and streets except freeways. It follows from this definition that strategic arterial traffic will be favored over that of conflicting cross-street traffic at at-grade intersections. The result of this favoritism in establishing intersection traffic controls is that a higher proportion of traffic signal green-time is allocated to the strategic arterial. The *quality* of traffic service furnished from the arterial and the crossing street is directly related to the allocation of green-time. The *amount* of traffic that can be carried respectively by the arterial and the cross street is a function of the allocation of green-time *and* the number of lanes passing through the intersection.

Establishing an effective and acceptable (to the affected community) balance of service quality between the strategic arterials and cross streets is probably the single most important decision to be made if a strategic arterial system is to be productive. This balance is achieved by the allocation of green-time at the signalized intersections. If the allocation of green-time to the cross street is insufficient to permit the level of service established for the crossing street, then consideration will have to given to providing a grade separation at the conflicting intersection.

For planning purposes, a general warrant for installing a grade separation at an existing at-grade intersection may be based on

(1) the quality of service along the crossing street whereby the allocation of green-time to the crossing street is insufficient to sustain the desired level of service, and
(2) the quality of service along the strategic arterial whereby the frequency of at-grade intersections is so high that the average travel speed along the strategic arterial is less than desirable.

In practice, this determination of locations of grade separations will be an iterative process. The process is diagrammed in Figure 6.1 and includes the following steps.

(1) Assuming that the maximum number of through-lanes have been provided and that the signal program has been optimized as to cycle and interval lengths and phase sequencing, input the demand volume and segment length. Segment length will consist of fairly homogeneous street sections between signalized intersections.
(2) To initiate the process, estimate the maximum possible green-time which can be allocated for through-traffic and input this to the model.
(3) Estimate the average travel speed based on the assumed signal settings and demand volumes. This is the most difficult step. Many existing models can be used for this, including the 1985 Highway Capacity Manual Procedure, TRANSYT, and TRAF-NETSIM Delay can be obtained from the TEXAS model. In choosing a model, care should be taken that the parameters of the model are not violated and that the application does not exceed the designed capabilities of the model. (A description for using the TEXAS model to estimate intersection delay is presented in a following section.)
(4) Compare calculated average travel speed with operational criteria set for strategic arterials. As suggested before, the criteria are an approximate free-flow speed of 40 mph and an average travel speed of approximately 30 mph, which is in the vicinity of

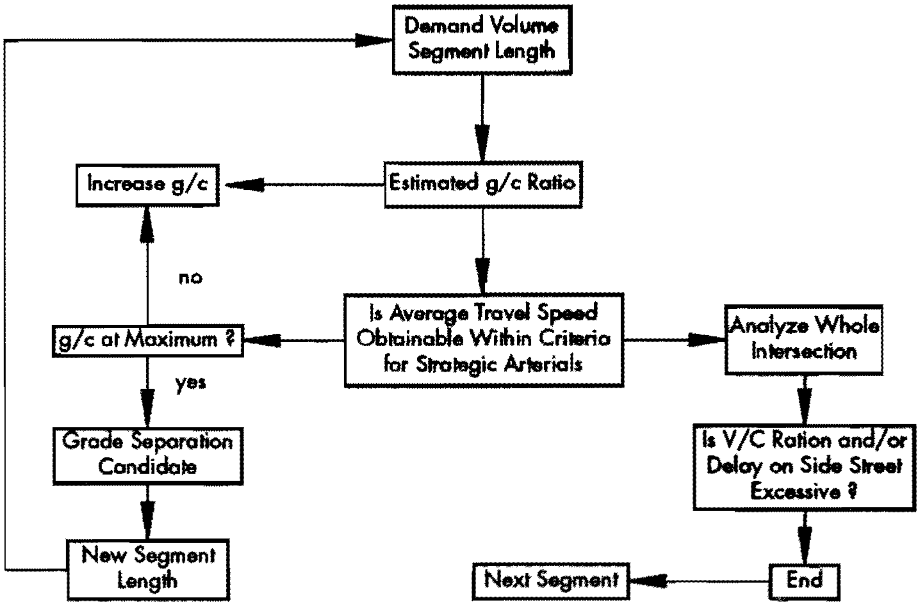


Figure 6.1 **Decision process for determining signal green-time and grade separation locations on strategic arterials**

the volume/capacity ratio of 0.9, with maximum flow rates of 800 to 1,000 passenger car equivalents per hour per lane.

(5) If the criteria are met, analyze the other approaches to the intersection. A simple approach, such as considering volume/capacity ratios, may suffice, or an analysis using the Highway Capacity Manual (HCM) methods can be made. The HCM is most applicable to moderate ranges of some of the parameters and may fail to capture traffic operations at extreme values, e.g., at very high or very low (g+y)/c ratios. Depending on how critical the case is, more detailed models, such as the TEXAS model, can be used.

(6) If volume/capacity ratios or delays on side streets are deemed unacceptable, consider a grade separation for the location. Other considerations that will be discussed may argue for or against the provision of a grade separation at a specific location. With a grade separation provided, increase the effective segment length and repeat the procedure from Step 1 for the longer segment to the next signalized intersection.

(7) If traffic operations at the intersection are considered adequate and the signal settings are considered suitable to provide traffic operations compatible with those of a strategic arterial, analyze the next segment.

(8) If the chosen signal settings do not provide for the target average travel speeds, green-time for the arterial street approaches must be increased, and the procedure could be repeated from Step 2, or it can be directed to Step 9.

(9) If the green-time at an intersection that is allocated to the arterial street traffic is considered to be the maximum tolerable, the intersection, or one upstream, is a candidate location for grade separation, which will increase the effective segment length, and the process returns to Step 1.

Application of the above procedure may appear to be tedious, but practice has shown that it is relatively simple as first and succeeding estimates converge rapidly to a resolution. A spreadsheet program is very useful in making these calculations because succeeding calculated values can be seen. The main difficulty is in arriving at the average overall delay, which is used to calculate average travel speed.

ESTIMATING AVERAGE TRAVEL SPEED

Travel speed (V) along a segment (between two signal-controlled intersections) of arterial can be expressed as

$$V = s/t \qquad (6.1)$$

where

s = segment length, and

t = average overall travel time.

Furthermore, V can be expressed by

$$V = s/[(s / v_d) + d] \qquad (6.2)$$

which is the average overall travel speed, where

v_d = unimpeded speed, corresponding to the average desired speed, and

d = overall average delay experienced, relative to the desired speed,

i.e.,

$$d = t - t_d$$

where

t_d = travel time at desired speed.

For the purposes of this analysis, it is suggested that the desired speed be set in relation to the overall design speed of the facility under consideration. As previously indicated, design speeds of 45 to 50 mph will be appropriate for strategic arterials, and a 45 mph average desired or unimpeded target speed will be appropriate.

An effort has been made to find a general relationship between demand volume, green-time, and overall travel time through an intersection. This relationship can be used in the planning analysis in lieu of undertaking multiple simulation runs for each case. The TEXAS model was used to simulate traffic movements through a typical intersection, using traffic volumes and green-time as the independent variables and overall travel time as the dependent variable. The default values given in the TEXAS model appear to yield realistic results. This was confirmed by several previous research efforts and during the development of the model (Ref 30). The following inputs were used.

(1) The vehicle stream consisted of only medium size passenger cars moving straight through the intersection. Input to the final model should thus be in terms of passenger car equivalents.

(2) Two lanes in each inbound and outbound direction were simulated to allow for some lane changes. In the analysis, all flows were expressed as per lane volumes to allow for extension to more lanes.

(3) The primary analysis was performed using a fixed cycle length of 80 seconds. Some further investigations of other cycle lengths were also done to estimate variation caused by cycle length and are discussed later.

(4) Yellow clearance interval was set to 5 seconds and the ratio of green-time plus clearance interval to the cycle length [(g+y)/c] was varied to be 0.3, 0.4, 0.5, 0.6, or 0.7.

(5) The speed limit and the average desired speed for each approach was set at 45 mph, with the 85th percentile desired speed set at 47 mph. This speed was chosen to correspond to the design speed and target travel speed considered appropriate for strategic arterials, as indicated above.

(6) Demand volume was increased in steps of 100 vehicles/hour/lane, from 100 vehicles per hour per lane to the apparent absolute capacity for each signal setting.

(7) Lengths of the approach and departure legs were set at 1,000 feet. This length affects the way the TEXAS model accepts vehicles for simulation, especially under conditions of heavy demand, and is related to maximum flow rates obtained from the model.

As would be expected, longer cycle lengths allow higher maximum flow rates but at the expense of higher delays, at least at low to moderate levels of traffic demand. Figure 6.2 shows the maximum flow rates obtained for the ratios of (g+y)/c and cycle lengths used. A plot of the overall average delays for different cycle length intersection spacings of 0.5, 1, 1.5, and 2 miles and (g+y)/c ratios of 0.5, 0.6, and 0.7 is shown in Figure 6.3. There is no apparent cycle length that clearly and under all flow conditions minimizes delay for single approaches, as is under consideration here. This does not imply that it is not possible to optimize cycle length in order to minimize delay simultaneously incurred by all approaches, as has been indicated by Webster (Ref 21) and is generally done in practice by the use of manual analysis or

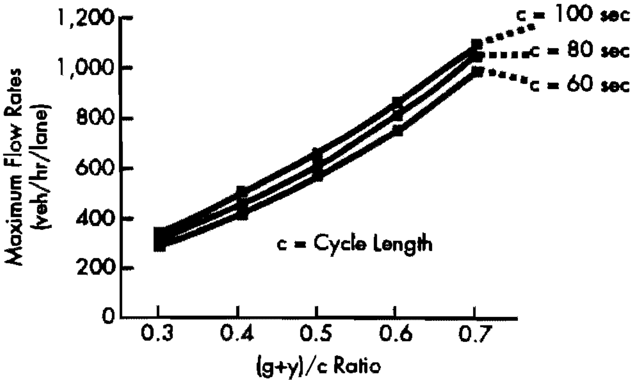


Figure 6.2 Maximum flow rate against cycle length and [(g+y)/c] ratios

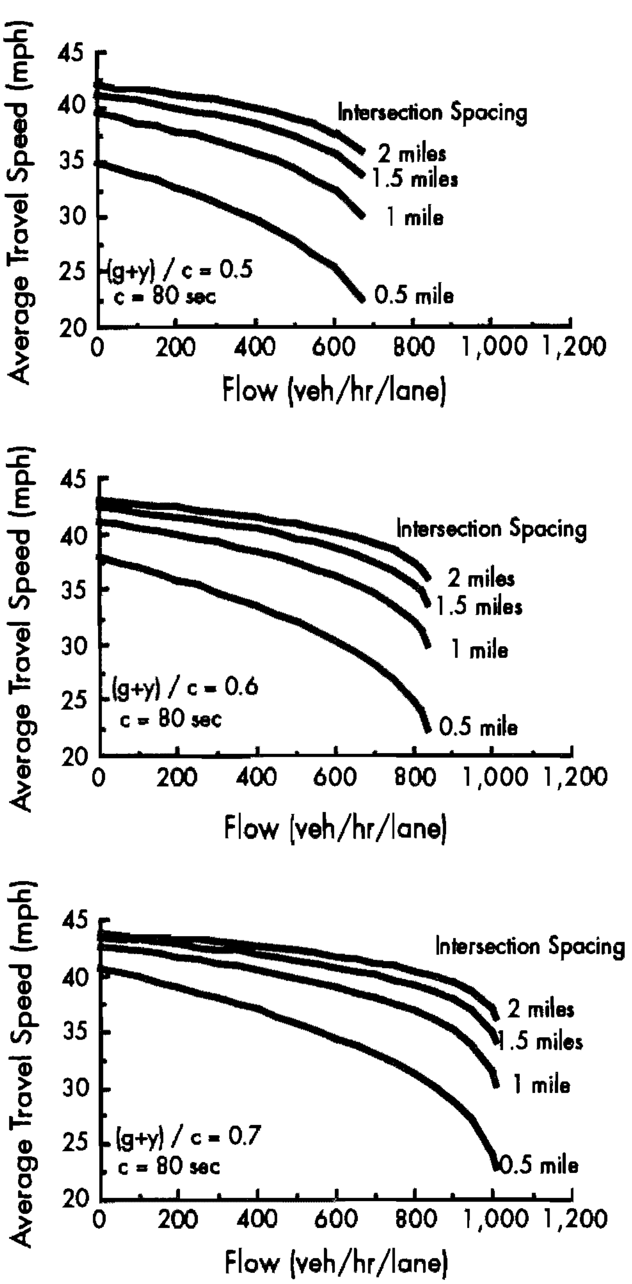


Figure 6.3 Average travel speed against flow for various intersection spacings and [(g+y)/c] ratios

the use of computer packages, such as TRANSYT, SOAP, or PASSER.

The TEXAS model was used in a mode to simulate *random* approaches and arrivals to the intersection. This analysis therefore does not consider the effect of platooned arrivals at the intersection, as would be the case with coordinated signals. The example of random arrivals was assumed because it reflected a more conservative or worst-case approach in that the delay incurred under these assumed conditions is likely to be greater than that for progressive or coordinated signal timing.

If the only delay being incurred is that caused by the traffic control at the intersection (i.e., if the delay, d, in Equation 6.2 consists only of intersection delay) and there is no mid-block delay, the above results can be used to construct average travel speed-flow relationships for various (g+y)/c ratios and intersection spacings. Some examples were generated and these are shown in Figure 6.3, which shows average travel speed against flow for intersection spacings of 0.5, 1, 1.5, and 2 miles and (g+y)/c ratios of 0.5, 0.6, and 0.7.

COORDINATION OF TRAFFIC SIGNALS AND VEHICLE ACTUATION

The approach outlined above is based on the assumption of random arrivals at each signalized intersection and fixed time cycles. Coordination of signals and use of vehicle actuation can and does improve traffic operations, particularly during conditions of light to moderate flows.

Coordination

As coordination of signals is used as standard practice on most arterial streets and has been the subject of many studies, it is not covered in detail here. It can be pointed out that coordination of signals is a relatively low-cost method for reducing delays, and efforts should most definitely be made to coordinate signals when they exist on strategic arterials.

It can, however, be pointed out that coordination may be less reliable in raising traffic operations to the stable levels of operation set as goals for strategic arterials, because coordination (1) does not increase the absolute maximum flow rates that can be handled on a facility, (2) is highly dependent on the retention of strong platoons between signals, and (3) is less effective in allowing higher travel speeds at higher flow rates, compared to lighter flow conditions.

The assumption of random arrivals would be the more conservative approach. The possibility of failure of the mechanical and electronic system controlling coordination should also be considered. Such events are not altogether rare, especially on newer and experimental systems, adding to the possibility that an unplanned incident will adversely influence the efficiency of operations on arterials. However, systems allowing the on-line monitoring of signal function can reduce the occurrence and consequences of failure of signal equipment.

Some of the characteristics of coordination mentioned above are shown in Figure 6.4. The data shown in the graph were generated by applying the model based on TEXAS model simulation results, above, and results from TRAF-NETSIM simulation.

For an arterial segment with two lanes per direction and traffic signals set for a fixed cycle length of 70 seconds and a (g+y)/c ratio of 0.6 for the arterial, four cases were analyzed using the TRAF-NETSIM model: (1) very good coordination, for example, the green band width equals the available green-time at all signals and has a slope equal to the average desired speed of the vehicles, set to 45 mph; (2) very poor coordination, generated by offsetting the start of phases on signals such that a vehicle traveling at its desired speed between two signals will arrive at each downstream signal while the red interval is indicated; and (3) each of the two cases above applied to segments with signal spacings of 1,000 and 2,000 feet.

Figure 6.4 shows, much as expected, that

(1) the procedure based on results from the TEXAS model for random arrivals yields values of average travel speeds between those for good and poor coordination;

(2) the efficiency of the coordinated system reduces more rapidly with increasing flows, compared to the poorly coordinated system; and

(3) because of platoon dispersion, the efficiency of coordination is lower over the longer spacing between signals, yielding average travel speeds only marginally higher than those based on the model assuming random arrivals, despite the fact that the desired speed distribution embedded in the TRAF-NETSIM model is fairly narrow.

Because of application of strategic arterials, efforts should be made to coordinate signals, but that will not be a sure way to reliably and absolutely increase efficiency, especially where signals are spaced well apart, as is necessary to afford strategic arterials the required level of operations.

Vehicle Actuation

As for the coordination of signals, the use of vehicle actuation at signalized intersections has been ignored in the discussion above. Vehicle actuation, and specifically semi-vehicle-actuated systems, with green-time reverting back to the arterial when there is no cross-street demand, will be very

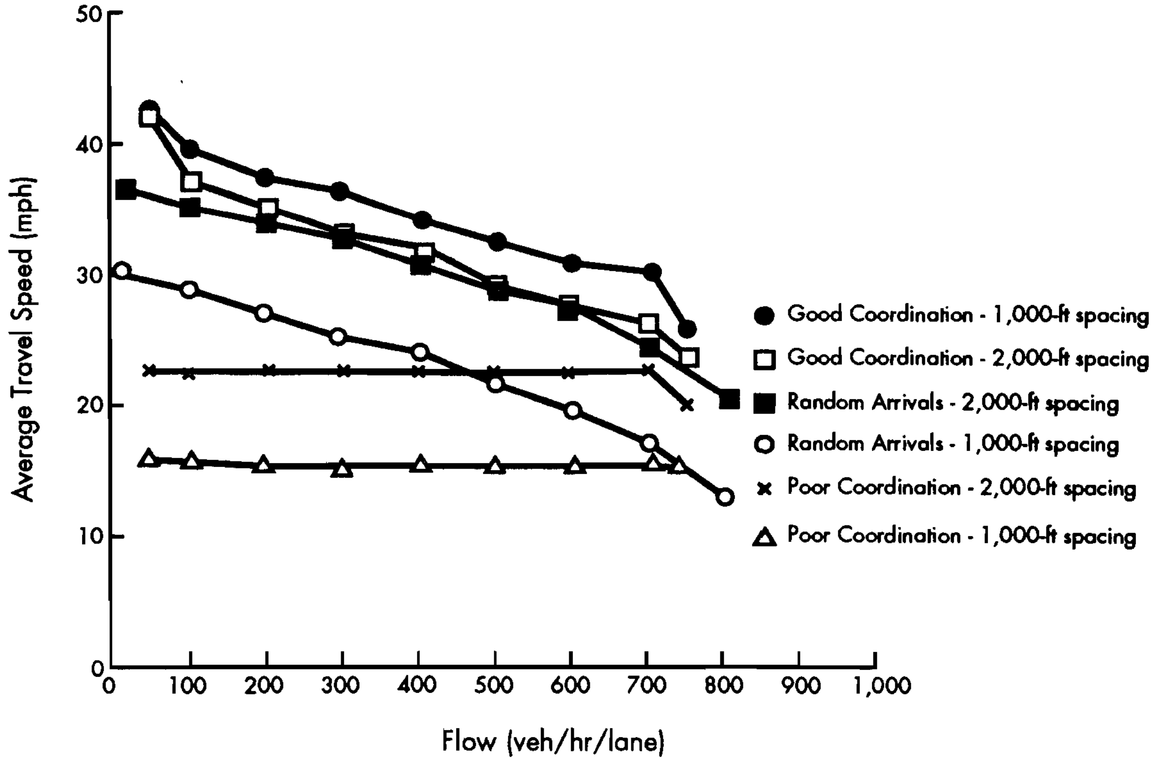


Figure 6.4 **Average travel speed against traffic flow showing effect of signal coordination and intersection spacing (Derived from simulations using the TEXAS and TRAF-NETSIM models)**

well suited to operations projected for strategic arterials. Much as with the coordination of signals, the efficiency of vehicle actuation diminishes under higher demands. With a fairly constant demand on cross streets, signal operations become similar to those of a fixed-cycle operation, with an assumption of fixed-cycle operation for planning purposes being the more conservative approach.

It is recommended that vehicle signal actuation be used at signalized intersections on strategic arterials. Allocating as much green-time to strategic arterials as is tolerable is in line with the criteria set for strategic arterials. The use of vehicle signal actuation can only improve strategic arterial operations. Most benefits will be derived when the cross-street demand for green-time is low. Vehicle actuation should also benefit users of the cross streets during off-peak traffic periods. The benefit would be a reduction in the probability of experiencing delay in crossing a strategic arterial caused by the high probability of encountering a red facing signal.

GRADE-SEPARATED INTERCHANGES

This section is directed to the *relevant* geometrics and *space* requirements for the design of grade-separated interchanges for strategic arterial streets. The only thing special about strategic arterial street interchanges is the likelihood that they will be constructed within an urban environment, where building space is limited, expensive, and perhaps difficult to acquire. There may also be the added complication of existing traffic passing near or through the construction site and the need to provide access to abutting property. Consequently, the proposed guidelines for the design of grade-separated interchanges address the *minimimum* geometric magnitudes needed to provide adequate traffic operational qualities and occupy a minimum of right-of-way.

More specifically, the guidelines address two important issues: (1) the minimization of space required for a grade separation structure, considering the scenario sketched for the most likely conditions in which strategic arterials will be applied, mainly along an existing arterial where major widening of the right-of-way is not possible, whether it is due to economic or physical constraints; and (2) the consistent application of appropriate standards for design and control on the arterial street, with the preservation of minimum levels of traffic operation in mind, which will, as stated before, include a consistent design speed of approximately 50 mph with provision made for safety.

These guidelines deal primarily with the physical design of arterial streets wherein it is presumed that a significant part of any resources dedicated to strategic arterial streets will be for grade separations. The justification or warrant for the installation of a grade separation at a particular location is not addressed directly in these guidelines. This is a subject beyond the scope of this study and is addressed by other research.

Function and Importance of Grade Separations

It is assumed that some of the strategic arterial street traffic will have to be grade separated if these arterials are to deliver the quality of traffic service that is desired. In an urban area of any size it would be extremely unlikely to find a route for a strategic arterial which did not cross a single traffic stream warranting a grade separation. When a grade separation is installed along an arterial the spacing between adjacent intersections is effectively increased or, to put it another way, the frequency of at-grade intersections is decreased, which in turn increases the average operating speed between the intersections. It is also assumed that some at-grade intersections can be designed to permit a satisfactory level of service on both the strategic arterial and the crossing street. The important issue in planning strategic arterials is to identify candidate sites, both existing and future, where grade separations are or will be needed so that installation can proceed with a minimum of inconvenience and additional expense.

The purpose of the grade separation is to remove some of the traffic from the intersection and out of the competition with the remaining traffic for the available green-time. Consequently, each of the remaining traffic movements will be eligible for a larger share of the green-time. For most cross streets, it is assumed that the traffic to be removed is the through (non-turning) traffic from the strategic arterial. If the cross street is another strategic arterial or equally important street, then a detailed analysis will be required to determine which of the intersecting street traffic streams should be grade separated. The analysis should be directed toward maximizing system benefits. If the crossing street is a freeway, then, in order of priority, the freeway traffic stream will be grade separated and that of the arterial will be accommodated by signalization. If a two-level grade separation will not provide adequately for the crossing traffic, then a three-level interchange should be considered. The usual configuration of a three-level interchange grade separates the through-traffic movements and accommodates all turning traffic at an at-grade intersection. Such an installation might be justified where a strategic arterial crosses a freeway.

GEOMETRICAL CONFIGURATIONS

There are many types of geometrical configurations of grade-separated interchanges which could be adapted for arterial streets. Any recent edition of AASHTO's *A Policy on Geometric Design of Highways and Streets* describes a variety of interchange types, any of which could be adapted to strategic arterials. Many of these interchanges require large amounts of right-of-way. As stated previously, these guidelines are directed toward a geometric design that requires a minimum amount of right-of-way, which limits the number of practical applications for strategic arterials. Many of the interchanges described by AASHTO involve three and four levels, and provide grade separations for some or all turning traffic movements, as well as the through-movements. The type of interchange postulated for strategic arterials, considering the amount and nature of the traffic, would generally be two-level, with the through movements grade separated and the turning movements accommodated through a signalized at-grade intersection. There may be instances when traffic volumes warrant the installation of a three-level interchange, such as when two arterials cross or when a strategic arterial crosses a freeway. The predominant type of interchange expected to be used in a strategic arterial system is the two-level diamond type, or some close variant. The diamond types are the Compressed Diamond and the Single-Point Diamond.

The Compressed Diamond is very similar to conventional diamond interchanges, with the exception that, because of space requirements, little or no provision is made for the storage of vehicles within the interior of the interchange or between the ramps. The interiors of two variations of the Compressed Diamond configurations are shown in Figures 6.5 and 6.6. The variation shown in Figure 6.5 does not provide a separate left-turn lane within the interior whereas the variation shown in Figure 6.6 does.

Two variations of the Single-Point Diamond (also called the single signal intersection) are shown in Figures 6.7 and 6.8. The geometrical layout for the Single-Point Diamond provides for simultaneous (same signal phase) left turns from the exit ramps (Refs 73, 74, and 75). Different geometric configurations can obviously also be provided with a variety of signal timing plans, and geometric layout and signal timing plans have been the subject of several studies (Refs 10, 73, 74, 75, 76, and 77). The variation in Figure 6.7 permits a straight-ahead or cross-intersection movement, whereas the variation shown in Figure 6.8 does not. The purpose of the straight-ahead movement is to permit traffic to gain access to property located on the far side of the intersection. The straight-ahead movement permitted by the configuration shown in Figure 6.7 requires a four-phase signal operation, whereas the configuration shown in Figure 6.8 requires only three phases.

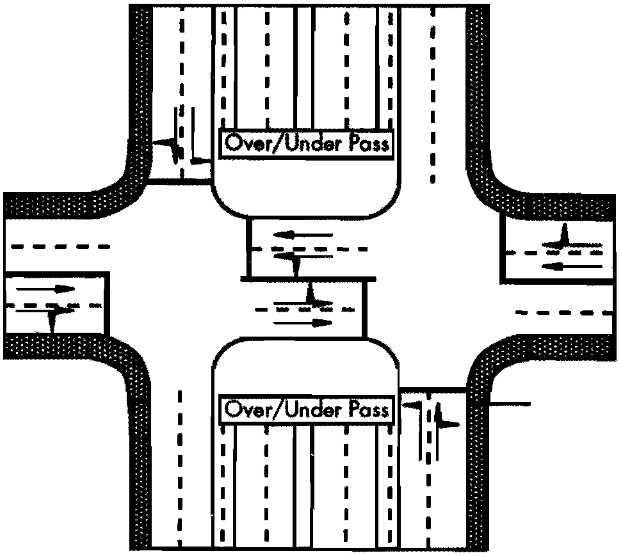


Figure 6.5 **Compressed diamond interchange without left-turn lanes on cross street (Source: Ref 73)**

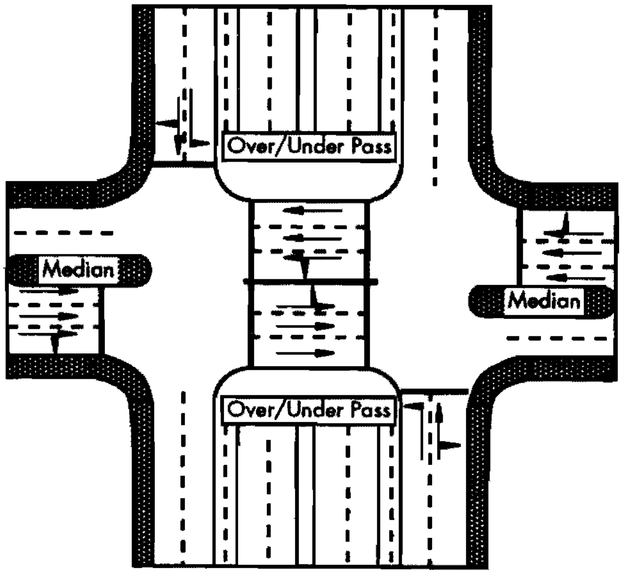


Figure 6.6 **Compressed diamond interchange with left-turn lanes on cross street (Source: Ref 73)**

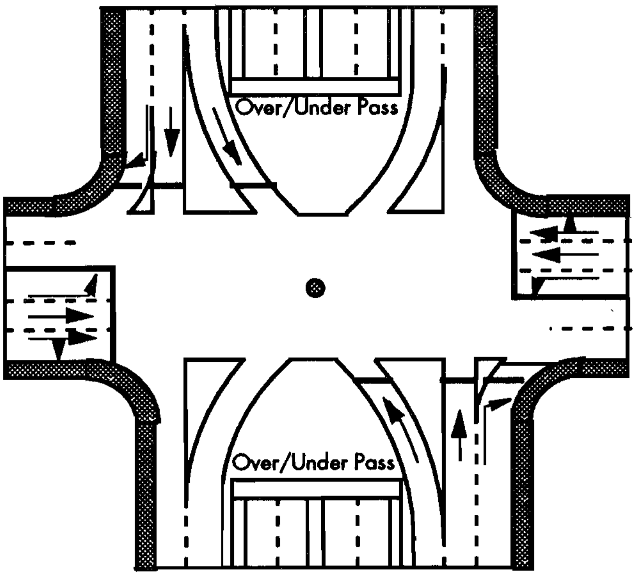


Figure 6.7 **Single-point diamond interchange with provision for straight movements from ramps (Source: Ref 73)**

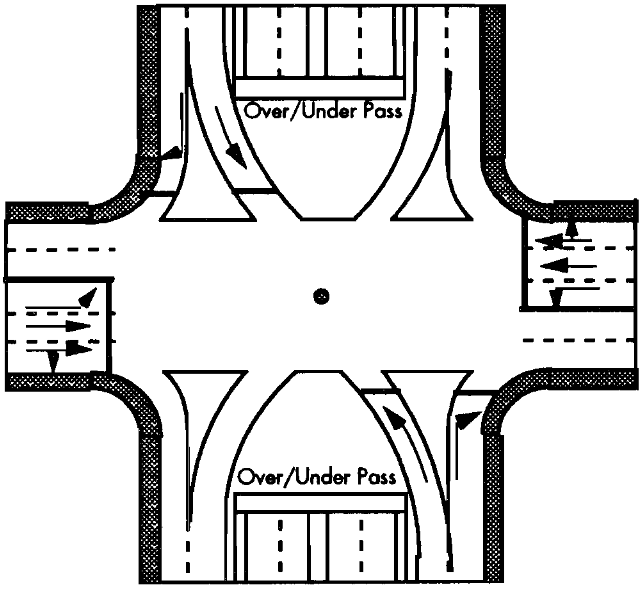


Figure 6.8 **Single-point diamond interchange without provision for straight movements (Source: Ref 73)**

GEOMETRIC AND RIGHT-OF-WAY REQUIREMENTS

GENERAL

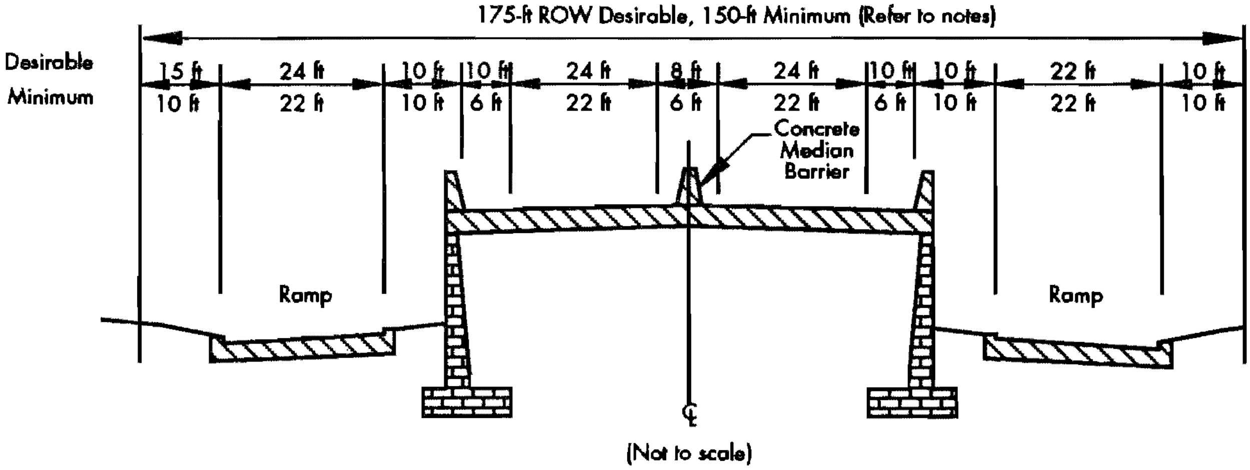
Good planning not only identifies the *location* of future interchanges but also provides guidance about the extent and shape of the *additional* right-of-way needed in order to install the interchanges. Right-of-way requirements for a strategic arterial grade-separated interchange are a function of (1) the cross section through the interchange, (2) lane and shoulder widths, (3) the profile length of the grade separation, and (4) normal right-of-way required outside the interchange area.

Lane and Shoulder Width

Bonilla and Urbanik (Ref 76) suggested *marginal, low,* and *high* levels of design standards which should be considered for arterial grade separations. The levels are characterized by differences in lane and shoulder width and median treatment. These differences have an impact on the capacity and design speed of the different types.

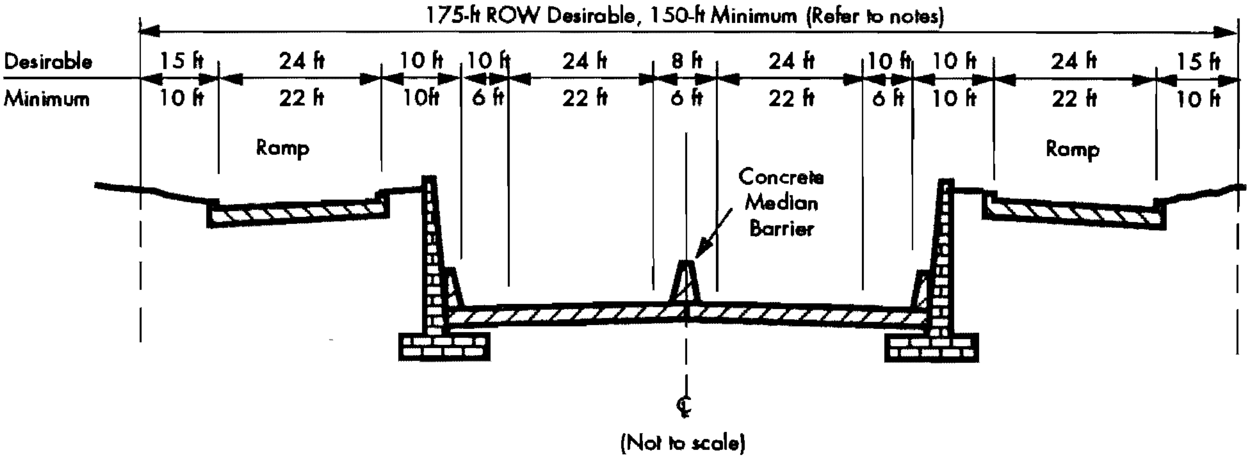
The lower design speeds on the marginal and low types are caused by the reduced widths of lanes, shoulders, and medians, all of which provide a less forgiving environmnent for drivers. The high-level facilities can handle higher design speeds because of a more forgiving environment featuring wider lanes, more clear distance to obstructions, more spacious recovery areas, and wider shoulders for emergency stopping. Of these design standards, considering the projected 50 mph design speed, only the higher-level design standards are desirable for strategic arterials. This design includes 12-foot lanes, 10-foot shoulders, and an 8-foot median. Figures 6.9 and 6.10 show recommended dimensions and overall right-of-way required for an overpass and an underpass, respectively. The use of minimum desirable dimensions should be reserved for the "hard" cases and where the amount of truck traffic is low. It is difficult to set absolute minimums such that the "no-build" choice would always be preferable to accepting, say, 10-foot-wide lanes. The "no-build" may be the worst choice, and a decision as to whether or not to reduce standards further may depend almost entirely upon the weight of the statistical null alternative.

At the other extreme, where right-of-way is not critical, consideration should be given to 12-foot-wide shoulders and 16-foot-wide medians. This additional width would not necessarily warrant a higher speed limit, but it would provide more space for future maintenance and rehabilitation work to be accomplished under traffic. At the final extreme, the additional width might permit restriping from two 12-foot trafffic lanes to three 11-foot lanes. This last alternative has been exercised too many times on freeways to be considered extraordinary or unlikely.



Notes: 1. Add 10 to 12 ft for speed-change lanes if there is land access to ramp.
2. Add 11 to 12 ft for each additional lane.

Figure 6.9 Cross section of arterial street approaching an overpass



Notes: 1. Add 10 to 12 ft for speed change lane if there is land access to ramp.
2. Add 11 to 12 ft for each additional lane.

Figure 6.10 Cross section of arterial street approaching an underpass

Grade Separation Length

The length required for elevating or lowering the roadway for an overpass or underpass can be determined by using the relevant required sight distances and allowable maximum grades corresponding to the applicable design speed. The applicable sight distances and vertical design elements have been covered above but are applied here to determine the required length of grade separations. Assuming horizontal approaches, equal grades on either side of the grade separation structure, and the use of a single vertical curve directly in the center of the grade separation, the total length of the elevated or depressed section is given by Reference 73.

$$L = 2(G(K_s+K_c)+T) \qquad (6.3)$$

where

T = the distance between sequential vertical curves

and

$$T = \frac{100H}{9} - G\left(\frac{K_s + K_c}{2}\right) + \frac{W^2}{8aK_i} \geq 0 \qquad (6.4)$$

where

K_s = required rate of vertical curvature for a sag,

K_c = required rate of vertical curvature for a crest,

K_i = Kc for an overpass and Ks for an underpass,

G = gradient of the approaches, percent,

H = required elevation above/below the level section, at the location of the crossroad vertical clearance window, feet, and

W = width of vertical clearance window, feet.

Consecutive vertical curves cannot overlap, so T must always be equal to or greater than zero. Flatter gradients or shorter curves may be necessary to fit the grade separation into the minimum space.

The minimum clearance under structures will depend on local regulations; AASHTO (Ref 18) recommends 14.5 feet as a minimum and 16.5 feet as a desirable clearance at the lowest point. The required elevation of the elevated or depressed roadway at the edge of the clearance can be determined by adding the depth of the structure deck, values of 20 to 25 feet being suitable for estimation. The elevation requirement can be relaxed where it is possible to alter the elevation of the street being crossed by a few feet and thus obtain the required vertical clearance. Such action will be very site-specific and unlikely to be applicable where an overpass is installed at an existing major intersection, but more likely to be of value at an underpass. In these cases the sight distances and comfort criteria should also be applied on the cross road as compatible with its design speed.

Using these values and the required sight distances and K-values described in Chapter 5, the length for the grade separation was calculated, using the maximum grades that would allow the proper fitting of curves (i.e., $T > 0$) for values of the required elevation of 15, 20, and 25 feet; widths (W) of 50, 100, 150, and 200 feet; and design speed values of 40, 50, and 60 mph. The low required elevation (15 feet) is an example of a case where it is possible to lower or raise the road being crossed by an overpass or underpass. The results are shown in Tables 6.1 and 6.2 for an unlighted overpass and underpass, respectively. It is noted that the maximum gradient to allow $T > 0$ is always less than or equal to the maximum gradient suited to the design speed. The evaluation also indicated that the total length of the grade separation and the proper fit of the curves are very sensitive to even small changes in the gradient. The maximum gradient is thus shown to the nearest 0.5 percent. The resulting required length is not sensitive to small changes in the K-values. For comparison, lengths are shown in Tables 6.3 and 6.4 for a brake reaction time of 1.5 seconds and for a lighted facility. Drivers on strategic arterials can probably be expected to react somewhat more quickly to their everchanging urban driving environment than will unalerted drivers on long stretches of rural highway. AASHTO policy recommends a 2.5-second brake reaction time for unalerted drivers. A lighted facility—as might be the case for a strategic arterial—eliminates the need to consider headlight distance controls, which require a larger K-value and consequently a longer sag curve. As shown in the tables, the differences in the lengths required for underpasses and overpasses are negligible. The grades and curves shown for the underpass are well within the requirements for sight distance underneath the structure. The guideline to keep gradients of intersection approaches to below 2 to 3 percent should be kept in mind (Refs 61 and 78).

Typical Overall Right-of-Way Required for Grade Separation

The maximum widths of required rights-of-way discussed above need not be applied over the whole length of the area where the arterial is elevated or depressed but can follow the taper of the ramps. The total right-of-way required for a grade separation will depend on local conditions, including the gradient of the approaching roadways and elevation and width of clearance required. A general case can be shown and this may provide adequate information for the first stages of a study of the feasibility of providing grade separation in a given location. The case taken is that shaded in Tables 6.3 and 6.4, namely the case of a 50 mph design speed, a minimum elevation of 20 feet, and a 50-foot width. The total length between VPC1 and VPT3 is thus 1,700 feet.

It is assumed that the ramps join and leave the through-lanes with a curve with a 5-degree (radius = 1,146 feet) minimum radius. This 5-degree curve is followed by a short tangent, followed by a reverse curve where the right-side pavement edge is 44 feet away from the arterial right pavement edge. It is also assumed that the retaining structure will start where the difference in elevation between the arterial and the ramp is 3 feet and that, at that point, a 26-foot separation between the right-side pavement edge is required for a wider lane in the gorge (14 to 16 feet) and adequate separation (10 to 12 feet). Results for the case described above are shown in Figure 6.11. Also

Table 6.1 **Length required for an overpass from level grade 2.5-second brake reaction time and unlighted facility**

						Length Required (ft)			
						Width (W) of Clearance Window (ft)			
Height or Elevation of Clearance Window (ft)	Design Speed (mph)	Maximum Gradient* (%)	Ks	Kc	Maximum Suitable Gradient (%)*	50	100	150	200
15	40	6	70	80	4	1,352	1,358	1,368	1,381
	45	5.5	90	120	3.5	1,594	1,598	1,606	1,616
	50	5	110	160	3	1,811	1,815	1,822	1,831
	55	4.5	130	220	2.5	2,076	2,080	2,085	2,093
	60	4	160	310	2.5	2,376	2,378	2,382	2,388
20	40	6	70	80	5	1,552	1,556	1,564	1,575
	45	5.5	90	120	4	1,841	1,845	1,852	1,861
	50	5	110	160	3.5	2,089	2,092	2,098	2,106
	55	4.5	130	220	3	2,384	2,387	2,392	2,398
	60	4	160	310	2.5	2,776	2,778	2,782	2,788
25	40	6	70	80	5	1,752	1,756	1,764	1,775
	45	5.5	90	120	4.5	2,057	2,061	2,067	1,075
	50	5	110	160	4	2,331	2,334	2,339	2,346
	55	4.5	130	220	3.5	2,654	2,657	2,661	2,667
	60	4	160	310	3	3,077	3,079	3,083	3,087

*Note: Maximum gradient is that gradient recommended by AASHTO to correspond to the design speed. Maximum suitable gradient is that maximum gradient required by the geometry of the vertical curves to avoid overlapping of curves.

K-values are given for 2.5-sec brake reaction time, and stopping sight distance at sag curves are determined by headlight sight distance.

Table 6.2 **Length required for an underpass from level grade 2.5-second brake reaction time and unlighted facility**

						Length required (ft)			
						Width (W) of Clearance Window (ft)			
Height or Elevation of Clearance Window (ft)	Design Speed (mph)	Max. Gradient* (%)	Ks	Kc	Maximum Suitable Gradient (%) *	50	100	150	200
15	40	6	70	80	4	1,352	1,359	1,370	1,386
	45	5.5	90	120	3.5	1,594	1,600	1,610	1,624
	50	5	110	160	3	1,812	1,818	1,827	1,840
	55	4.5	130	220	2.5	2,077	2,083	2,092	2,106
	60	4	160	310	2.5	2,377	2,381	2,389	2,400
20	40	6	70	80	4.5	1,566	1,572	1,582	1,596
	45	5.5	90	120	4	1,842	1,847	1,856	1,868
	50	5	110	160	3.5	2,089	2,094	2,102	2,114
	55	4.5	130	220	3	2,385	2,390	2,398	2,409
	60	4	160	310	2.5	2,777	2,781	2,789	2,800
25	40	6	70	80	5.5	1,736	1,741	1,749	1,760
	45	5.5	90	120	4.5	2,058	2,062	2,070	2,081
	50	5	110	160	4	2,331	2,336	2,343	2,353
	55	4.5	130	220	3.5	2,655	2,659	2,666	2,676
	60	4	160	310	3	3,078	3,082	3,088	3,098

* Note: Maximum gradient is that gradient recommended by AASHTO to correspond to the design speed. Maximum suitable gradient is that maximum gradient required by the geometry of the vertical curves to avoid overlapping of curves.

K-values are given for 2.5-sec. brake reaction time, and stopping sight distance at sag curves are determined by headlight sight distance.

Table 6.3 **Length required for an overpass from level grade, 1.5-second brake reaction time, and lighted facility**

Height or Elevation of Clearance Window (ft)	Design Speed (mph)	Maximum Gradient* (%)	Ks	Kc	Maximum Suitable Gradient (%)*	Length Required (ft) Width (W) of Clearance Window (ft)			
						50	100	150	200
15	40	6	40	50	5.5	1,043	1,050	1,061	1,077
	45	5.5	50	80	4.5	1,253	1,259	1,267	1,279
	50	5	60	120	4	1,471	1,475	1,482	1,491
	55	4.5	70	160	3.5	1,663	1,667	1,672	1,680
	60	4	80	230	3	1,931	1,934	1,938	1,944
20	40	6	40	50	6	1,209	1,215	1,225	1,240
	45	5.5	50	80	5.5	1,444	1,448	1,455	1,465
	50	5	60	120	4.5	1,700	1,704	1,709	1,717
	55	4.5	70	160	4	1,921	1,924	1,929	1,936
	60	4	80	230	3.5	2,229	2,231	2,235	2,240
25	40	6	40	50	6	1,375	1,382	1,392	1,407
	45	5.5	50	80	5.5	1,626	1,630	1,637	1,647
	50	5	60	120	5	1,901	1,904	1,909	1,917
	55	4.5	70	160	4.5	2,147	2,150	2,154	2,160
	60	4	80	230	4	2,491	2,493	2,496	2,501

*Note: Maximum gradient is that gradient recommended by AASHTO to correspond to the design speed.
Maximum suitable gradient is that maximum gradient required by the geometry of the vertical curves to avoid overlapping of curves.
K-values are given for 1.5-sec brake reaction time, and stopping sight distance at sag curves are determined by comfort criterion only.

Table 6.4 **Length required for an underpass from level grade, 1.5-second brake reaction time, and lighted facility**

Height or Elevation of Clearance Window (ft)	Design Speed (mph)	Max. Gradient* (%)	Ks	Kc	Maximum Suitable Gradient (%) *	Length required (ft) Width (W) of Clearance Window (ft)			
						50	100	150	200
15	40	6	40	50	5.5	1,043	1,052	1,066	1,086
	45	5.5	50	80	4.5	1,254	1,263	1,277	1,296
	50	5	60	120	4	1,473	1,480	1,493	1,512
	55	4.5	70	160	3.5	1,665	1,672	1,685	1,703
	60	4	80	230	3	1,933	1,940	1,953	1,972
20	40	6	40	50	6	1,209	1,217	1,230	1,248
	45	5.5	50	80	5.5	1,445	1,451	1,463	1,479
	50	5	60	120	4.5	1,701	1,708	1,720	1,736
	55	4.5	70	160	4	1,922	1,929	1,940	1,956
	60	4	80	230	3.5	2,230	2,237	2,248	2,264
25	40	6	40	50	6	1,376	1,384	1,397	1,415
	45	5.5	50	80	5.5	1,626	1,633	1,645	1,660
	50	5	60	120	5	1,902	1,908	1,919	1,933
	55	4.5	70	160	4.5	2,148	2,154	2,164	2,178
	60	4	80	230	4	2,492	2,498	2,508	2,521

* Note: Maximum gradient is that gradient recommended by AASHTO to correspond to the design speed.
Maximum suitable gradient is that maximum gradient required by the geometry of the vertical curves to avoid overlapping of curves.
K-values are given for 1.5-sec brake reaction time, and stopping sight distance at sag curves are determined by by comfort criterion only.

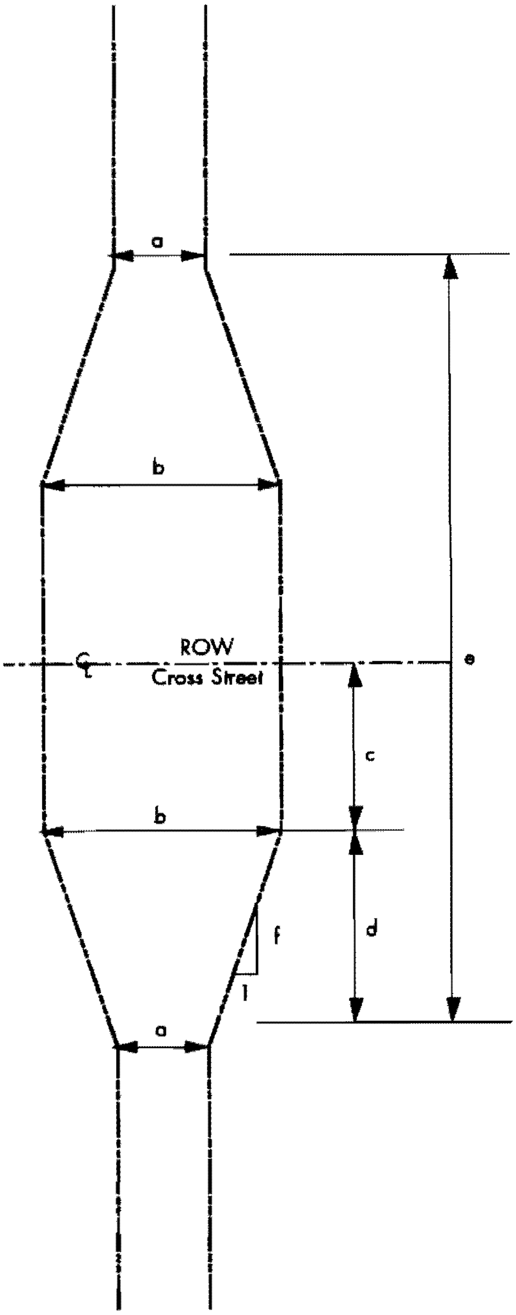


Figure 6.11 Right-of-way required for a typical arterial street grade separation

included are values to be added for slightly different configurations.

Existing guidelines for the taper, where a lane is added at a ratio of 1:10 (Ref 60), are considered slightly low, and an increase of this value to 1:15, to provide better operations and also to conform to values for deceleration lanes (as covered in Chapter 7), is preferred. Lane drops with a taper of 1:40 (Ref 60) are adequate but should be increased if possible. Adequate warning of lane drops is essential.

The configuration shown in Figure 6.11 provides adequately for acceleration and deceleration distances on ramps, as recommended by AASHTO (see Table 6.5).

HANDLING OPPOSED LEFT TURNS

Storage Bays and Left-Turn Phases

In the previous sections, attention was primarily given to the movement of through-traffic on the arterial, but opposed left turns, which require protected turning opportunities, do have a major impact on the green-time available for through-traffic.

The Left-Turn Analysis Package (LTAP) is based on Center for Transportation Research Reports 258-1 and -3F (Refs 79 and 81). The LTAP covers warrants for the provision of left-turn bays and left-turn signal phases or both. Commensurate with the operations on strategic arterials, it is recommended that exclusive lanes be provided for all left turns.

The addition of left-turn phases reduces the available green-time for the strategic arterial through-traffic, and it may be impossible to provide left-turn phases as well as adequate green-time for the through-traffic. Time allocated for left-turn phases can be reduced by optimizing the sequence and operation of left-turn phases. A study on phase sequencing (Ref 80, among others) found that permissive left turns allowed in addition to protected phases are always beneficial in terms of delay, regardless of type of control (fixed-time or actuated) or of sequencing. Maximum approach speeds projected for strategic arterials may be 45 mph or greater. Such speeds, with considerations for traffic safety, may argue against the use of permissive left turns.

Table 6.5 **Minimum acceleration and deceleration lengths for entrance and exit terminals**

Design Speed (mph)	Assumed Speed Reached (mph)	Full Lane Acceleration Length (ft)	Average Acceleration Rate (ft/s/s)
40	31	380	2.7
50	39	760	2.2
60	47	1,170	2.0

Design Speed (mph)	Assumed Average Running Speed (mph)	Full Lane Deceleration Length (ft)	Average Deceleration Rate (ft/s/s)
40	36	315	4.4
50	44	435	4.8
60	52	530	5.5

(Source: Reference 18)

Another way of reducing the required left-turn time is the use of dual left turns. This approach does, however, require a very wide median at the intersection approaches. Marcus (Ref 82) found that there is very little difference in the operations of dual left turns and single left turns, viewed on a per lane basis, the main difference observed being that saturation flow per lane at dual turns is about 90 percent of that for a single-lane turn.

One way to allow maximum through green-time and provide for a narrow median is to prohibit left turns at the intersection and to provide for indirect left turns.

Indirect Left Turns

The use of indirect left turns by providing jug handles has been discussed previously. Below are the main advantages of indirect left turns.

(1) They eliminate the need for a left-turn phase at a signalized intersection to handle the left-turn traffic from the strategic arterial to the cross street. If the cross-street traffic does not involve a high percentage of turns onto the arterial, a two-phase signal should be adequate.

(2) There is no need for a left-turn lane or bay, and the use of indirect left turns facilitates the use of a narrow median, which reduces right-of-way requirements.

(3) Additional right-of-way for jug-handle turns is required only at left-turn intersections.

(4) As all turning movements are made from the outer one or two lanes, the need for lane changes and for weaving and merging maneuvers is reduced.

In addition, there are disadvantages:

(1) The right-of-way required is at intersections, which in urban areas are usually the most expensive business properties and most likely to be already developed.

(2) The use of existing street blocks to provide for indirect left turns reduces right-of-way requirements but increases travel times and distances for left-turning vehicles, and the use of other streets for this purpose may encounter public objection.

The offset required at jug-handle configurations is determined by estimating the queue length on the cross street, and, as shown by Lin et al (Ref 79) and Marcus (Ref 82), the TEXAS model provides very good estimates of queue length under various conditions and can be recommended for this application.

The most important benefit of indirect left turns is that they can be used consistently at all intersections where left turns are allowed, or at least at a number of consecutive locations, where driver expectancy can be used. Violation of this principle can lead to driver confusion and erratic and hazardous maneuvers.

CHAPTER 7. ACCESS MANAGEMENT

GENERAL

The functional classification assigned to a particular highway should be related to the character and quality of traffic service provided. The two primary functions of highways are (1) to afford mobility, and (2) to provide access to land. Unfortunately, these two functions conflict so that to provide more of one is to diminish the effect of the other. The freeway is at the top end of the functional classification scale and has very limited accessibility and characteristically provides high-quality traffic service. This contrasts with the local street, where access controls are the perogative of individual property owners and where parking is usually unrestricted. Ranked between freeways and local streets are arterial streets and collector streets. The strategic arterial street is proposed to be designed and operated to fit in between freeways and ordinary arterial streets. This relationship is shown graphically in Figure 7.1.

The quality of service tolerable to a highway user for any trip is conditioned by the trip length and the value of the trip: the travel conditions and environment which might be considered tolerable for a short trip might not be the same for a longer trip. Good highway planning and design recognize the tolerance and capabilities of highway users and should strive to provide the type of facility appropriate for each trip demand. The local street is at the bottom end of the scale and affords tolerable conditions for *short* trips. It follows that highways designed for long trips are more than adequate for short trips. The opposite is, of course, not true. A well-planned and designed system of highways should match its functional characteristics to the quality of service that is tolerable to the user for each link in a trip.

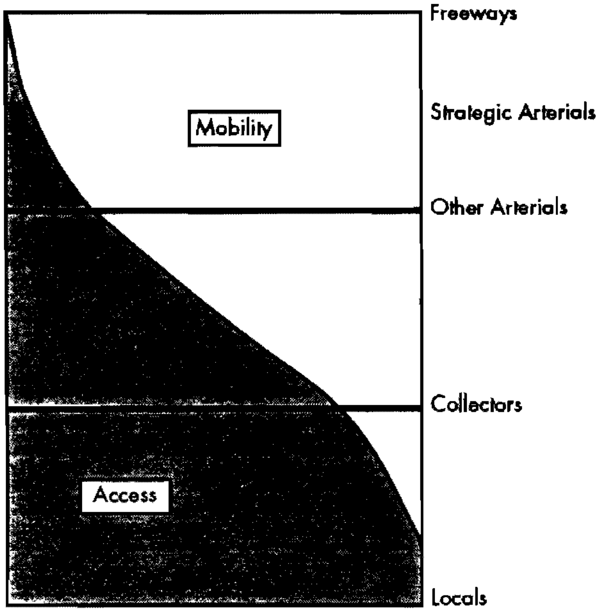


Figure 7.1 Basic roles of roads and streets

Because function and service quality are related, quality and, hence, function are also products of design and access. Design and access control are interrelated in that one method of controlling access is through design. The intensity of access can have a significant effect on highway operations as well as on land use. Therefore, access control affects not only the quality of traffic service but abutting property interests. The management of access embraces a wider range of concerns than simply the issue of highway users: because of this complexity, the issue of managing access is treated separately. This chapter addresses the consequences of access control and access management as well as the design of some access control measures. Although the effects of design on traffic operations and service have been treated in preceding chapters, this chapter addresses only those elements of design having a direct effect upon ingress to and egress from abutting property.

Strategic arterials are most likely to be developed along existing streets, where driveways exist or where abutting properties have a legal right of access to a public street. The emphasis on strategic arterials is to provide mobility. Thus, the application of ironclad operating criteria designed to limit and control access to the strategic arterials is essential if the mobility function is not to be compromised. Although access *can* be controlled by regulations and by physical design, access can also be *decontrolled* unless those responsible maintain a commitment to provide high-quality traffic service.

Legal, social, and political factors also play a role in the control of access. It is evident that some degree of reasonable exceptions to both geometric design and access controls may be required if plans for a strategic arterial system are to meet the test of public and political acceptability. However, it is also evident that these exceptions should not be binding beyond the life interest of those seeking advantages in access. A strategic arterial street system can be very cost-effective if the desirable operational standards can be secured and maintained. The benefits of the same system, however, can be significantly reduced if too many exceptions are granted for access reasons.

"Access management" as used herein is the control of access and land use through the application of regulatory measures and geometric design. The term was chosen to contrast with the more common term "access control." Technically speaking, there are varying degrees of access control, and freeway facilities are, for example, often referred to as "access-controlled" facilities. The latter term has been associated with freeways only and might convey the impression that a strategic arterial street should have the same degree of access control as a freeway, which is not the case. Access management, for these guidelines, has to do with the manner and method of controlling access to strategic arterials.

THE DILEMMA

As a matter of survival, businesses that front on arterial streets and depend on transient traffic for clientele are inclined to be concerned about convenient access to their properties; however, they may be less concerned about the effect of this accessibility on traffic operations. Furthermore, ideas for improving the overall effectiveness of an arterial street for the general welfare—usually at the cost of inhibiting some local access—will, in all probability, be opposed by property owners whose interests, although transitory, are nevertheless perceived by them as vital. These basic conflicts between private and public interests, even though they may be more imagined than real, preclude obtaining that cordial political and public consensus desirable for planning and improving public works.

Proximity and easy access to a traffic stream are valuable assets to many businesses and are accordingly reflected in property values and rental costs. Additionally, there is intense competition among traffic-dependent businesses for accessible property along busy thoroughfares. These competitors are not likely to view sympathetically measures that inhibit or regulate access to their properties. Such actions can have a detrimental effect not only on their incomes but also on the market value of the affected properties. Thus, it is easy to understand why some commercial interests react vigorously and negatively to government attempts to control or regulate access. Herein lies the principal reason that access control is difficult to plan and administer.

The heart of this issue is the conflict between public and private interests. This issue is difficult to resolve because private interests are usually perceived much more intensely than the public interest. The private interests will affect fewer people but more intensely. The public interest usually affects more people, although less intensely. However, taken as a whole, the public will most likely derive more benefit from access restriction than private interests in aggregate will forfeit.

Freeway design and operations exemplify how traffic management and access control yield, on balance, public benefits and acceptance. There are net advantages to the intrusion of freeways into the urban architecture even though access between the freeway traffic and adjacent property is always indirect and often circuitous. The public apparently accepts this inconvenience of access as tolerable since it is unknown, or at least extremely rare, for a controlled-access road to be downgraded to a lesser degree of access. However, acknowledgment of these economic and operational advantages will not always ensure that plans to control access will be successful. Furthermore, it remains true that the few who perceive economic injury will be zealous in their efforts to avoid access restrictions

An answer to this dilemma is to control and to channelize access through geometric design and traffic operations. The degree of access control and channelization needed is a function of operating speed and geometric design. Access control should be applied and managed system wide. All traffic-dependent and competing interests should be subject to similar access restrictions. These restrictions should be managed and administered so that the degree of access allowed is a function of its effect on traffic and the amount of traffic affected. It would follow that the more intensely an arterial is used the more restrictive the access requirements.

Access controls should be concerned with the frequency, location, and geometric design of access facilities. Controls should also take into account the concurrence of peak traffic periods with periods of peak traffic movements to and from abutting property. The science and craft of measuring and managing traffic operations is well advanced and there is reason to believe that transportation professionals will be able to achieve the desired degree of access control for each affected property along each arterial route.

There are many street-accessible services that are useful and desirable to the motoring public for which, under appropriate control, access can be provided without significantly inhibiting traffic operations or property interests. Traffic management decisions should be based upon defensible measures of operations and safety considerations, taking into account also the desirability, where feasible, of property access. Public and political support are important in planning and managing access regulations. Large amounts of political capital may have to be expended in order to apply controls where the property interests involved are hostile. Public and political capital are nourished by the reasonableness of applying access controls and should not be squandered on inconsequential applications of regulations. When the public interest is considerable, however, the first concern should be to apply the controls necessary to secure the maximum benefits to traffic operations.

It does not necessarily follow that channelizing or otherwise controlling access will have a bad effect on abutting property. Appropriate geometric design, access location, and access time can return benefits for both the public and private interests. The difficulty will be in persuading property users of this possibility. All property owners fronting arterials should be apprised of the general benefits to commercial interests in upgrading the system. System-wide improvements of arterial operations will certainly extend the equal-trip-times boundaries of accessibility. Business will benefit from becoming more accessible to a much larger clientele territory even though transient access may have to be restricted.

ACCESS CONTROL THROUGH LAND-USE CONTROL

The operation of an effective highway and street transportation system requires some degree of control over access. The intensity of access is in turn linked to land use. Consequently, access can be controlled by controlling land use. It then follows that the functional classification of a street facility should determine the level of land-use control applicable to the property abutting the street. NCHRP Report 31 (Ref 88) provides an overview of types of land-use control techniques, which also covers control of access.

The report indicates that normally accepted land-use control techniques fall into four major groups:

(1) eminent domain,
(2) police power,
(3) contractual agreement, and
(4) the doctrine of nuisance law.

Eminent domain is the right of government to acquire private property rights. Since access rights are a property right they can be purchased by governmental agencies. Although this is a highly effective way of controlling land use and/or access, it can be expensive. It is, however, a technique that can be most effective when used to acquire rights-of-way within urban areas that are not highly developed and are relatively inexpensive. The best reason for long-range systems planning is that the instituting of access rights along strategic arterial routes is much less expensive and controversial prior to extensive land development. Developers can adapt their interests much easier to a nascent system than to a system which has been established after the fact.

It might be desirable to purchase *limited* or *partial* access rights in order to control or channel traffic to abutting property. The *limit* could relate to the degree of physical access, such as the number, location, width, and configuration of ingress and egress points. The limit could also relate to the *period* of access. The sale of property access rights is generally considered total within certain metes and bounds. Limited purchase might be an equitable way to compensate property interests if access control is applied retroactively. Where developed property abuts a street whose functional classification is changed, say upgraded to a strategic arterial, there may be a compensable interest to such property if access is additionally restricted.

There is also a case for the purchase of *temporary* access rights—a device that could be useful during construction operations when providing even temporary access to abutting property could be awkward and expensive. The access to be purchased might be partial or total with respect to ingress or egress of traffic, but could be limited in *duration*. Such a device would be useful in allaying anxieties of abutting property interests, whose principal anxiety might be about loss of access during construction operations rather than about the access allowed to and from a completed facility.

The purchase of limited rights might also be considered a means for defining and extending the limits of access control by police powers, which is considered by some as somewhat arbitrary and difficult to apply equally. Similarly, property restricted by limited access by previous purchase may be considered eligible for additional compensation if subsequent restrictions are required in the interest of traffic operations. The purchase of limited rights is seen as a method of settling disputes arising between access rights and access control. The value of limited access rights is seen as similar to the capitalized value of leasehold rights or perhaps air rights, which are restricted. In summary, the value of property may be diminished by access control and, in lieu of buying whole properties or total access, the purchase of an abridged interest appears to be expedient and equitable to both the public and private interests.

Police power can be used to restrict, zone, and regulate land use through the approval processes for subdivisions and building permits. Marks and Spitz (Ref 88) note that this technique has been tested in court and found to be enforceable without compensation to the affected land owner. However, the application of police power is much less restrictive than eminent domain and, in general, is much less effective. Zoning controls the location, size, intensity, and type of land use and is the most widely known application of police power. Zoning is, however, not intended to establish permanence but to stabilize land use for a reasonable period, as it reflects the short-range land-use desires of the community. An example of zoning control would be limiting development to that compatible with existing and future transportation facilities. This example could exclude land uses that depend upon commercial traffic but could include specific requirements for on-site parking requirements and driveway connections to the adjacent highway (Ref 18). Control of subdivisions has a direct impact on access control, since it offers a way to restrict the quantity and location of access points to specific highways. Police powers, through the permitting process, are also used to regulate curb cuts and driveway locations and spacing (Ref 18).

Marks and Spitz (Ref 88) highlight some of the inefficiencies of the application of police power: "The basic disadvantage is their [police power's] potential instability, particularly excessive flexibility dependent on local whims and lay officials.... Police power can be an effective device if used, but in many communities its application is either limited or subject to considerable variance as pressures develop, both politically and economically."

Contractual agreements, which may or may not involve compensation to a land owner for services rendered, can be used to minimize unwanted development of land. The doctrine of nuisance law relies on a legal interpretation to prevent land use which is seen as damaging to the highway and correspondingly being against the best interests of the community. According to Marks and Spitz, contractual agreements and the doctrine-of-nuisance law are rarely used. Police power and eminent domain are the two most prominent tools for controlling land use (Ref 88). For the establishment of strategic arterials, the placement of restrictions on direct property access to highways without necessarily prohibiting access is a technique that could be implemented through negotiation and agreement between the highway authority and landowners.

Marks and Spitz note that both the public and the courts have accepted access prohibition to certain highways and to freeways as a general fact but that access control and limitation for other highways and streets are not that widely accepted. These are some reasons for this state of affairs:

(1) In cases where property has access to only one public thoroughfare, denial of driveway access would constitute a "taking" of the property and the owner would have to be compensated. In some cases, notably freeways, this problem has been overcome by the provision of frontage roads.

(2) Some communities are unwilling to deny or control access to speculative real estate developments fronting on a major thoroughfare because of the fear of losing tax revenue if the development becomes unattractive to investors because of denial of access. There are compromises that can be made to remedy this problem, such as providing special access facilities to the development. If the development is large enough, a grade-separated interchange access facility might be negotiated, with the developer sharing in the cost.

(3) Access limitations create restrictions for development and for that reason are often strongly opposed by developers.

(4) Some cities do not have sufficient staff to analyze the interaction between access and traffic operations, to negotiate compromises with developers, or to persuasively argue the detrimental effects of lack of access control on the development.

(5) There are *changes* over time in the functional characteristics of a street and the land use of the abutting property. These changes should be recognized and compensated for, if necessary, by additional access controls. An arterial street adequately serving local traffic might be inadequate to serve the future demand for more trips of longer length.

(6) Limitations on access which appear to be unreasonable, or at least unacceptable, may not be defended vigorously by those responsible and may consequently prove to be unenforceable and ineffective in protecting highway utility over extended periods of time (Ref 88).

One of the most critical problems in managing access is continuity over the long haul in maintaining adequate controls. In the case of freeways, the acquisition of access rights or built-in provisions of alternative access provide protection which is not subject to deterioration over time. When fidelity to access control regulations is largely self-imposed by property interests and enforced by police powers, there is always the danger that the desired level of controls will erode over time unless the enforcement authority is especially vigilant. Maintaining controls under continual and increasing pressure by self-interests for additional access will always be difficult. The hope is that land use will eventually conform to the access controls and that property interests will recognize that self-interest is also served by the public interest. There is an interaction between land use and land-use controls. Conformation of land development to access is best exemplified by the adaptability of property interests to freeway access. Freeways, which are much more restrictive with respect to access than are strategic arterials, are relatively inaccessible. Nevertheless, the advantages of proximity to a freeway greatly outweigh the disadvantages of indirect access. The increased values of property adjacent to freeways testify to the disparity between the advantages and disadvantages. These advantages are due entirely to the quality of service afforded by the freeway system and any depreciation of access control which affects the quality of service will also diminish property values.

The establishment and maintenance of access and operational control standards for strategic arterial street systems should be protected by statute authority. The statute should circumscribe the rights of access of property abutting arterial streets and define the allowable relationship between operating speeds and accessibility. This is necessary to insure uniform interpretation of operating and access standards among various owners and to inhibit the issuance of too many variances to standards by owners. The form and implementation of such regulations is outside the scope of this study, but the notion is addressed in Chapter 10.

SOME LEGAL ASPECTS OF ACCESS RESTRICTIONS

The legal aspects of access restrictions have been investigated, specifically in the late 1950's and early 1960's, when the Interstate Highway Program was getting underway. It is assumed that the findings of these investigations which were related to freeways will also be relevant to any access restrictions applicable to strategic arterial streets. The case of the strategic arterial is complicated by the likelihood that these facilities will occupy existing rights-of-way for which access has been more or less uncontrolled. The incorporation of these rights-of-way will, in some cases, require retroactive restrictions of access. Such restrictions, which may or may not be held as a "taking," may have to be purchased. If the cost of acquiring the *degree* of access rights needed to obtain a desirable level of operations is relatively high, then the attractiveness of strategic arterials as low-cost improvements diminishes. It is possible that some of the loss in convenience to a property because of access restrictions would be more than offset by the enhanced value of the property because of its location on a major thoroughfare. It is postulated that in this instance the damages to the property because of access restrictions are offset by the increased value of the remainder.

The legal aspects of access control are thus also an area requiring further investigation. The following are two of the important legal aspects of access control.

(1) Each state, county, and city has authority to deny, control, and alter access to those public roads subject to their jurisdiction. Two interests are involved: (a) the right of the public to safe, efficient, and reliable travel along public roads is not subordinate to the rights of ingress to and egress from property abutting public roads, and (b) owners of property abutting public roads have the right to suitable and sufficient access. The objective of access control management is to accommodate both of these interests.

(2) Property rights, including right of access, should be protected from negligent and arbitrary infringement. The right of access is not, however, paramount to the public's right to safe, efficient, and reliable travel along public roads, and access rights may be purchased or regulated by the government.

The State of Colorado Highway Access Code, described in Chapter 3, is an excellent example of how legal requirements and regulations can be combined with the physical design and control characteristics of the roadway to provide access control on arterial streets.

ACCESS CONTROL THROUGH DESIGN CONTROLS

The ultimate objective of geometric design controls is to provide relatively permanent physical restraints to access violations. Geometric design includes the horizontal configurations, vertical profiles, cross sections of the roadways, and shape and location of curbs, barriers, delineators, signing, and pavement markings. All of these geometric elements can be configured and positioned to enhance access controls.

REACTION TO IMPLEMENTATION OF ACCESS MANAGEMENT

There will be opposition to access management measures. This applies particularly to the restriction of access and the restriction of turning movements. The most intense opposition will come from business interests dependent on attracting passing traffic for their existence. The business sector is also politically influential and will exercise this influence to obtain favorable treatment in disputed actions concerning access restrictions and driveway locations serving their property irrespective of the legal standing of the actions. It is essential in planning an arterial system that each candidate route be inspected for potential conflicts with the existing and proposed land use. It is hoped that if the routes can be established before land-use patterns are firmly established, arrangements can be made through negotiations with affected property owners to accommodate both public and private needs. Also to be considered is the response from other affected residents, public transit agencies, and local governments. The latter can include concerns about travel time and navigation of emergency vehicles (Ref 92).

From various sources, Stover and Koepke (Ref 48) accumulated information on selected generators and the percentage of trips they attract from passing traffic. The high percentage of attraction from passing traffic indicates generators' possible dependence on passing traffic and the magnitude of the effect that access restrictions will have on these commercial establishments and, correspondingly, on potential opposition. Small shopping centers, service stations, fast-food outlets, and convenience stores are highly dependent on passing traffic. Also noteworthy is the relatively high percentage of passing traffic attracted by supermarkets and medium-size shopping centers. A recent study in central Florida (Ref 93) on traffic generated by convenience stores with gas pumps indicated that an average of 69 percent of patrons interviewed were passing by the store and entered to buy gas or goods. Service stations and convenience stores are usually strategically located to be highly visible and accessible from more than one direction, such as at the intersection of two heavily trafficked routes, further complicating the task of restricting and limiting access.

It should, however, be pointed out that access management can also be beneficial to businesses and other developments located along or near arterials. If it becomes frustrating or hazardous to use the arterial or driveways located on it, persons may be less inclined to use that business. Developers of large shopping centers are, for example, becoming more aware that the continued traffic-carrying capabilities of the arterial street are essential to the long-term success of their developments and have shown an increased willingness to work with local officials in the location and design of access points (Refs 53 and 55).

Although the impact of access control on non-users has been extensively researched, there are no clear indications of its effect. The issue is complicated by normal cycles in the economy and the fact that, although some highway improvements restrict access, they also increase safety, provide greater mobility, and attract larger traffic volumes, which in turn stimulate economic activity. NCHRP Report 93 (Ref 53) presents a number of specific studies on the question of non-user impacts of highway improvements. A recent study, which included a literature review and a survey of transportation and traffic engineers in state highway departments or city governments, found no documented evidence to substantiate claims that raised medians cause business failures, other than when the business was orientated to drive-up patronage (Ref 92).

The application of continuous median barriers and a system of indirect left turns in New Jersey is described in Chapter 4. In some locations the system has been in place since the 1960's and land use has adapted to the system. New Jersey officials reported that objections from the commercial sector have mostly been based on the decrease in access associated with the system. Where the system has been installed, a drop in turnover in the first year was reported by some enterprises, but after that time previous levels were restored or exceeded. The retrospective reaction from businesses has also been that they actually benefit from additional traffic safety on the street on which they front, as well as by safer access to their locations.

After-studies on the State of Colorado Access Control Demonstration Project, discussed in Chapter 4, revealed that most of the dissatisfaction with the implementation of access control came from the business/retail sector, specifically from those that lost left turns, with business owners who had only indirect access prior to the project giving favorable or indifferent ratings to the project. In some cases, the response of business owners toward the project as a whole was prejudiced by their experience of a loss of business, including loss which occurred during the construction period. Generally, those who suffered most were older-style small businesses on small lots. These businesses experienced difficulty in establishing internal circulation and improved parking. The project was well received by residents of the areas, who mostly felt that reduced through-traffic and increased safety outweighed the inconvenience of more circuitous routes. The development sector received the project well, with the primary concern being the operation and design of their key access. Indirect benefits to local governments, through increased safety and capacity, were seen to translate into growth, increased land values, and reduced capital expenditure through better utilization of an existing facility (Ref 51).

It can be expected that reaction to access control measures on strategic arterials will be mixed and highly dependent on local circumstances. Cognizance of the sources of support and objection is necessary in both the selection of a strategic arterial location and the choice of the level of regulations and geometric controls to manage access.

SPECIFIC TECHNIQUES TO MANAGE ACCESS

Overview

Glennon et al (Ref 83) present a comprehensive overview of techniques to control access and conflicts at commercial driveways. Not all these techniques would allow or be compatible with the operational characteristics projected for strategic arterials. However, some of these techniques, applied consistently at all driveways along a strategic arterial, would go a long way toward minimizing the negative effect of driveway access along an arterial.

Designs and Controls Incompatible with Strategic Arterials

There are geometric designs and operating controls which may be commendable for use on lower classes of roadways that are not recommended for use on strategic arterials. Obvious examples are the regulation of speed to suit driveway operations or a deliberate attempt to meter and slow traffic by the installation of traffic signals. Unless a traffic signal can be installed at a driveway to a major generator and still allow the target travel speeds on the arterial to be maintained, the access to the development should be denied. The solution for access problems generated by a major traffic generator abutting an arterial may be the installation of a grade-separated interchange. The method of justifying a warrant for a grade-separated interchange is not essentially different from that for an at-grade intersection.

The installation of two-way left-turn lanes and continuous left-turn lanes and the provision of median storage for left-turn egress vehicles will have the effect of not only allowing but encouraging mid-block left-turn operations, which is not considered appropriate for strategic arterials. The use of curbed barriers to channelize traffic to discourage undesirable weaving and change-of-mind lane-switching is discouraged even though these movements are themselves undesirable. Pavement delineation is recommended for such channelization. Curbs used for channelizing purposes are considered hazardous. This is especially relevant considering the relative high speeds planned for strategic arterial streets.

GENERAL CATEGORIES OF GEOMETRIC DESIGNS AND OPERATIONAL CONTROLS

The geometric designs and operational controls applicable to strategic arterials are categorized as

(1) median treatments to restrict and control direct left turns,
(2) improving access movements to driveways,
(3) controls to limit the number and spacing of access points,
(4) geometric design of driveways to ease the negative effects of turning movements,
(5) internal planning for traffic circulation, and
(6) the special case of adapting one-way pairs to provide strategic arterial street service.

The above categories are discussed in greater detail in the following sections.

(1) Median Treatment to Restrict and Control Left Turns

Continuous Median Barrier

Although it is possible to control left-turn movements using only signs and pavement markings, vigilant law enforcement is required, and in practice may be unavailable. Installation of a continuous physical barrier within the median restricts turning movements effectively and permanently. The barrier also enhances safety by physically separating opposing traffic. Prohibiting left turns from property does cause a certain amount of inconvenience and it is desirable to provide the facilities and opportunities for U-turns at regular intervals. The purpose of U-turns is to afford reasonable access to property otherwise denied by the presence of the median barrier. The frequency of left-turn facilities depends on local conditions. Spacings of approximately 1/2 mile are prefered on applicable facilities in New Jersey.

Limiting Turning Movements by Median Treatment

Where it is not possible to eliminate left turns, some treatments allow restricted left-turn movements. Figure 7.2 shows a treatment where left turns into the driveway are allowed and left turns from the driveway are prohibited. This arrangement is not ideal for strategic arterials but can be used where there is a specific need to provide access to a property from both directions. Necessary conditions include a median of adequate width to provide a turning bay, and sufficient storage space to mask queuing is absolutely essential. A similar arrangement can be made to allow *left turns from*, but not into, the driveway. Such an arrangement is, however, not recommended for application to strategic arterials unless the intersection is signalized or an acceleration area is provided for left-turn egress vehicles. Such a median configuration would require a median width of at least 14 feet.

Figure 7.3 shows a treatment to permit *left turns into and from* driveways. This treatment is not recommended for strategic arterial streets except on an interim basis when traffic volumes are low. Not shown is the acceleration lane for departing (egressing) vehicles mentioned in the preceding paragraph.

(2) Improving Access Movements to Driveways

Mid-block access via left turns is not recommended, but an exception may be made if such access is in an interim phase in which arterial traffic volumes are relatively low. If mid-block access from strategic arterials is permitted, an adequate deceleration and storage area is considered essential. Analysis models, such as the Left-Turn Analysis Package, will be helpful in determining the length of the storage area. For the type of median treatments shown in Figures 7.2 and 7.3, a curbed median barrier is recommended rather than a painted median. The curbed barrier is considered self-enforcing.

Increasing curb return radii within the dimensions generally used for driveways and street intersections has only a marginal effect on turning-entry speeds. Based on test-track results, Richards (Ref 87) showed that with a wide (35-foot), unrestricted turning-entry driveway, average speeds increased linearly from approximately 10 mph to 13.5 mph, with an increase in radius from 0 to 30 feet. With a narrow entry width (10 feet), the corresponding speeds were from 3.2 mph to 8.5 mph. A similar indication can be obtained when considering the turning speeds based on side-friction, as used by AASHTO (Ref 18). It was found that vehicle paths tended to parallel the entry curb-line at driveways that had a curb return radius of 20 feet or more but to diverge from the entry curb-line where radii were less than 20 feet. Drivers tended to make wider turns both on the approach and inside the driveway to compensate for the smaller

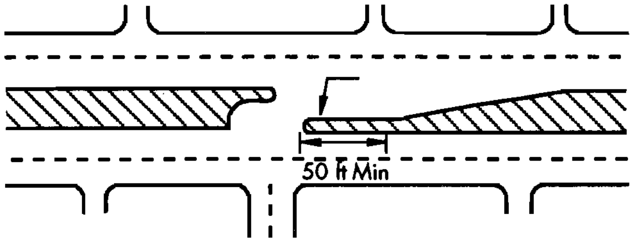


Figure 7.2 Median channelization to restrict left-turn egress maneuvers (Source: Ref 83)

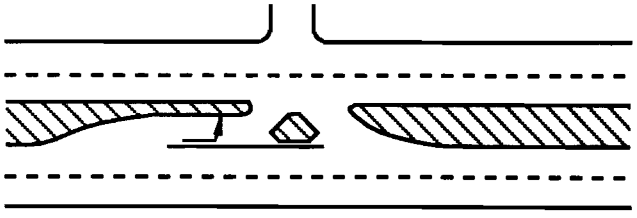


Figure 7.3 Channelization to control left-turn egress (Source: Ref 83)

radius (Ref 94). This is a reasonable result considering the minimum inside turning radius of 13.5 feet of the AASHTO design passenger car (Ref 18).

The use of a 20-foot curb return radius as an absolute minimum is recommended, with 30 to 50 feet preferred, to provide for heavy vehicles, since the Single Unit Truck design vehicle has a minimum inside turning radius of 28.4 feet.

Providing a right-turn deceleration lane for turning vehicles in their approaches to a driveway (C17) or cross street will minimize the friction between the turning vehicles and through-traffic. The curb return for the driveway or cross street should have an adequate radius so that the turning vehicles can enter the turn at at least 10 mph. The driveway or turning lane should also be of sufficient width so that turning vehicles will not further decrease speed because of a width restriction.

It has been found from observation that a vehicle shifting from a through-lane to a parallel deceleration lane in approaching a right-hand turn will reduce speed by about 10 mph upon completion of the maneuver (Refs 83 and 96). Once in the deceleration lane, the vehicle will further slow to about 10 mph upon turning into the driveway or cross street. A vehicle leaving the through-lane to turn into a driveway or cross street typically executes three sequential maneuvers.

(1) Assuming an initial 45-mph travel speed in the through-lane, the vehicle shifts one lane laterally to the deceleration lane and reduces speed to 35 mph at a deceleration rate of 4.8 ft/sec^2. The calculated deceleration length for this maneuver is 180 feet in 3.1 seconds. This 180 feet represents the length of uniform taper required to accommodate a speed reduction from 45 to 35 mph and a lateral shift of one lane width.

(2) The 35-mph speed in the deceleration lane is further reduced to 30 mph at the rate of 4.8 ft/sec^2 in anticipation of the turn. The calculated distance needed to execute this second deceleration maneuver is 73 feet.

(3) The 30-mph speed in the deceleration lane is reduced to 10 mph at a rate of 6.7 ft/sec^2 in anticipation of the final turn into the driveway. The calculated distance needed to execute this third deceleration maneuver is 128 feet.

These calculations suggest that a vehicle traveling at 45 mph and desiring to exit to a driveway or cross street would require a 180-foot taper plus a deceleration length of 200 feet (73 plus 128 feet rounded to 200) in order to enter the turn at the driveway at 10 mph. This result corresponds well with AASHTO's (Ref 98) guideline for a lane-change taking three to four seconds, independent of speed, and with Stover's (Ref 96) suggested use of a 120-foot taper and a 250-foot full lane. In test-track studies, Richards (Ref 94) found that there is no significant difference between a direct taper and a spiral design in terms of the driveway entry speed. The use of right-turn deceleration lanes is recommended for all intersecting cross streets and driveways on a strategic arterial. In the case of intersections, such a lane can also be used as a storage lane to enhance right-turn-on-red operations and for right-turn vehicles waiting for crossing pedestrians.

Provisions for a right-turn acceleration lane (C12) are less critical than for the deceleration maneuver, because vehicles turning from the driveway into the traffic stream will usually wait for an acceptable gap. It will, however, have benefits in reducing driveway delays and differentials in speed between through-traffic and driveway traffic in cases of heavy traffic flow, where the frequency of acceptable gaps is less. Based on accepted normal acceleration rates (see Table 7-47, Ref 95), the acceleration distances from 0 to 40 mph and 50 mph are 358 feet and 612 feet, respectively. Reports on the Colorado Access Control Demonstration Project (Ref 51) indicated that the acceleration lanes are not used to their full potential, because drivers tend to enter the through-lanes directly whenever a gap is available. Drivers tend to use the lanes when expecting long delays and when they know the lanes are of adequate length or continuous between succeeding intersections. Drivers may be hesitant to use the acceleration lanes if they sense that such use provokes them to merge into traffic in a short distance.

The minimum calculated length of a deceleration lane preceding and an acceleration lane following a driveway for a highway speed of 45 mph is in excess of 800 feet. Such a length is an ideal, which is seldom provided in practice within an urban environment. The use of a continuous auxiliary lane to serve as both a deceleration and an acceleration lane is more feasible. In effect, if driveways are closely spaced, deceleration and acceleration spaces overlap and drivers have to maneuver to avoid conflicts. This is probably less critical than it appears, because the methods used for calculating deceleration and acceleration tapers and lane lengths were derived for freeway driving conditions.

Freeways, which can accommodate 1,800 or more vehicles per lane per hour for an average headway of 2 seconds or less, require small speed differentials between exiting and entering traffic for efficient operations. If exiting traffic is not afforded a sufficiently long deceleration lane in order to slow down after leaving the through-lane, an exiting vehicle will have to slow down in the traffic stream in order to accomplish the departure maneuver. This decrease in speed in an intensely trafficked freeway lane will send a shock wave through upstream traffic and induce congestion.

A driver of an entering vehicle needs to accelerate to close to through-traffic speed in order to merge into a small time-gap. Consequently, entering and merging traffic needs a sufficiently long acceleration lane. On the other hand, busy major arterial streets normally accommodate 900 to 1,000 vehicles per lane per hour, providing headways of about 4 seconds or about twice that normally found in freeway traffic during peak traffic hours. The availability of these longer headways makes exiting and entering substantially less critical than is the case for freeway operations.

Provision for continuous auxiliary lanes or shoulders on strategic arterials is a principal element of strategic arterials. Although driving rules allow for the use of a shoulder as an area for leaving the through-lane to execute a right turn, it is recommended here that the shoulder area be used actually to formalize this function and make such use compulsory. Although auxiliary lanes are used in some locations, their application, signing, and regulation are not formalized in guidelines or in the *Manual on Uniform Traffic Control Devices* (Ref 67). This omission should be the subject of further investigation. Although auxiliary lanes can and should function as *emergency parking shoulders,* they also function as *speed change lanes.* Emergency parking shoulders are distinguished from auxiliary lanes in that motorists should be *discouraged* from driving on emergency parking shoulders, whereas motorists are *encouraged* to use auxiliary lanes for maneuvering. This is an important distinction, and signing and delineation should reflect the distinction accordingly.

Among the design features applicable to auxiliary lanes it is recommended that auxiliary lanes be a minimum of 11 feet wide, with a width of 12 feet or more preferable. All-day parking restriction should be applied on these lanes. Pavement markings should be white, conforming to the convention of white markings separating traffic flow in the same direction and yellow markings separating traffic flow in opposite directions. Yellow markings are also used to mark the left edge of the pavement on divided and one-way roads. Frequent white arrow markings and appropriate signing should be used. Two possible lane marking types are suggested: (1) parallel solid and broken lines, similar to those used for continuous two-way left-turn lanes, with the solid line on the driver's right (this arrangement is analogous to that used for painted median continuous turning lanes and signifies the lane's combined permissive and restrictive character); or (2) a broken line with shorter, wider dashes (e.g., 3-inch-long by 6-inch-wide stripes spaced 12 inches apart, similar to those which can be used at lane drops) to distinguish it from conventional broken lane markings. Markings and signs which may be appropriate for use with continuous right-turn lanes are shown in Figure 7.4. Stover and Koepke (Ref 48) recommend that auxiliary lanes be terminated at signalized intersections by a channelizing island which forces all traffic in the lane to turn right at the intersection. This is shown in Figure 7.4.

(3) Controls to Limit the Number and Spacing of Access Points

The principal objective of access management is to limit access to as few points as possible while taking into account property rights of access. In fact, traffic operations are affected by the *intensity,*

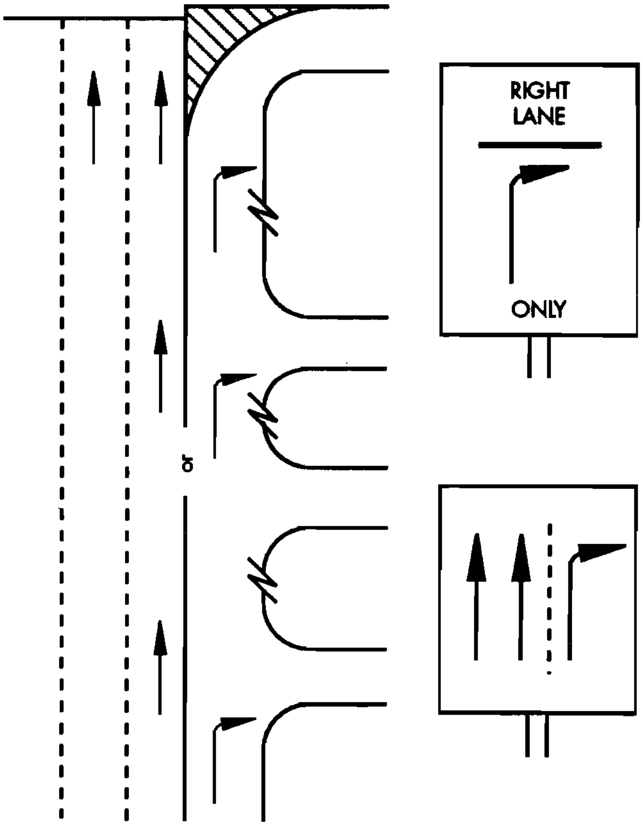


Figure 7.4 **Suggested layout, signs, and markings for continuous exclusive right-turn lanes**

time, and *location* of traffic movements to and from abutting property rather than by the *frequency* of access points. This statement may appear to be in conflict with the objective of keeping the number of access points to as few as possible. However, it is possible that fewer driveways handling large volumes of traffic during peak traffic hours can be more disruptive than more driveways handling small volumes of traffic during off-peak hours. Nevertheless, the *frequency* of access is easiest to measure and manage and is usually used as the standard for evaluating access. In general, the fewer the number of access points, the less traffic friction. However, if variances in access controls are granted, such factors as *intensity, time, and location* of driveway movements, as well as the strategic arterial traffic intensity, should be considered in evaluating the merits of variance.

Although property is guaranteed access to public streets, unlimited access may not necessarily be a given legal right. A review of literature on this subject has disclosed several specific issues, techniques, and guidelines relevant to assessing and limiting access which should be useful for drafting appropriate regulations.

(1) One suggestion is to allocate the number of driveways as a function of the length of available frontage. Guidelines suggest a maximum of one driveway per 600 feet of property frontage (Ref 83), which corresponds well with indications of access spacing and acceleration and deceleration distances discussed previously. Where the frontage is 600 feet or less, a maximum allocation of one access point per property is recommended. It is also recommended that once an access permit is issued on the basis of allocation, additional permits should not be allocated if the property in question is further subdivided. Such prohibitive regulations covering future subdivisions of property allow for and encourage suitable driveway placement as future development takes place, including use of shared access as discussed below.

(2) Inversely, if adjacent properties which were granted separate access permits are consolidated for one purpose, access should be reallocated according to the 600-foot rule.

(3) Consolidation of access for adjacent properties is a technique that has been suggested, but little success has been reported. Mandating such a technique, rather than negotiating, is loaded with legal problems: therefore, it should be no surprise that its application has been minimal. Another reason is that there is too little motivation from public agencies and developers to vigorously pursue its application. If this technique is successful, it should encourage the consolidation of adjacent properties into single ownership for purposes of access control. This technique may also ecourage cooperative agreements between neighboring developers in order to share access rights.

(4) If reasonable access can be furnished to a side or cross street rather than to the strategic arterial, then regulations should deny access to the arterial. Depending on the location of the strategic arterial in relation to other streets, driveway access onto the arterial can be significantly reduced by such a regulation. Legal and political problems may be encountered, but this technique can be effective.

(5) Denying access to small frontages may result in severe legal problems unless alternative access is available, an arrangement for suitable compensation can be made, or consolidation with adjacent properties can be arranged.

(6) Buying abutting properties is always an option but falls slightly outside the scope of strategic arterials in that costs can be excessively high. It can, however, be considered for smaller tracts of land, which can be put to a suitable use or offered for resale to adjacent properties and consolidated.

Over the longer term, regulations and steps to limit access to strategic arterials, including strict implementation and enforcement, have the potential to encourage the development of land use on fronting properties which are compatible with strategic arterial operations, location, and general goals. The classic example of land use adapting to highway access is along the Interstate Highway System. In this instance, although access has been stringently limited and is often circuitous, competition for property abutting these highways has increased its value disproportionately to that fronting non-controlled access highways. The lasting compensation to abutting property interests for losing immediate access is an increase in access to a larger system of streets and market area.

Placement and Physical Control of Access Points

The placement and requirement of a physical barrier to prevent uncontrolled access is necessary to stabilize access management over time and to reinforce driver expectancy on strategic arterials. Fences, other barriers, and curbing can be used to accomplish this. The barrier can be placed on the pavement or shoulder edge, in the case of curbing, or on the property boundary during redevelopment. Where on-site parking is adjacent to the highway, such a physical barrier will take on the shape of an island to prevent uncontrolled access between the parking area and the highway. The requirement to install a barrier on the property boundary should be included in the regulations associated with the designation of strategic arterials and enforced for new development during development approval and authorization.

It is also desirable to establish minimum corner clearances between driveways fronting the strategic arterials and adjacent cross streets. The object is to minimize conflict between driveway traffic, particularly exiting traffic, and traffic movements to the cross street. Another important reason is to ensure that traffic queues extending upstream from the intersection do not block driveways. Distances offered by various guidelines (Refs 48, 83, 96, and 102) are based on or are a repetition of the findings of NCHRP Report 93 (Ref 53). For a highway speed of 45 mph, which is applicable to strategic arterials, the guidelines suggest a clearance of 450 to 600 feet at the near side of intersections and 400 to 550 feet at the far side. The severity of conflict between corner driveways and intersection traffic is also a function of the coincidence of peak traffic movements from the arterial street and the corner driveway. Ideally, if traffic movements to and from the corner driveway peak at time periods different from those along the arterials, then the conflicts will be less and the minimum corner distance is less critical. It would be unusual in a mature urban area to find corner properties large enough to enable driveways to be set back from the intersection some 500 feet. Where the desirable setback cannot be obtained, an additional investigation into the specifics of the potential conflict should be made. The object of this investigation should be to mitigate the consequences of the conflict insofar as resources permit. For instance, if the level of service on the approaches to the intersection is reduced sufficiently by conflicting driveway movements, consideration should be given to prohibiting driveway exit movements.

Regulation of minimum property clearance is usually based on providing the minimum spacing of driveways consistently through the system, and the minimum property clearances are set to approximately half of the minimum driveway spacing. Regulation minimum property clearance is mostly applicable to new driveways, where spacing can be optimized during the permit authorization stage, but the concept should also be borne in mind when existing driveways are evaluated.

(4) Geometric Design of Driveways to Ease the Negative Effects of Turning Movements

Appropriate geometric driveway design can enhance traffic operations to and from and within driveways by providing unambiguous paths for turning vehicles, a smooth ride transition between the arterial street and the driveway, and visual guides. These measures can increase entering and exiting speeds, reduce driver uncertainty, and consequently reduce friction in driveway traffic and between arterial traffic and driveway traffic. The following paragraphs describe several design features which will be useful in designing driveways.

(1) The driveway width is a function of the type of vehicle designed for the entering and exiting speeds, curb return radii, desired offset distances, and angle of entry or departure. Driveway traffic can be channelized by curbs to prevent involuntary excursions. In general, the desired width can be determined by using the appropriate vehicle turning template and adding whatever width is desirable for passing a stalled vehicle. The provision for passing a stalled vehicle may be omitted if the channelization curbs are mountable, and the surface behind the curbs is paved; otherwise it is better to make the driveways wider.

(2) Existing guidelines suggest lane widths corresponding to those used on minor streets, namely 16 feet for single-lane driveways and 11 to 12 feet where two-way and multiple entry or exit lanes are present (Refs 51, 53, 83, and 102). These values assume that curb radii are adequate for vehicles to follow the curb line without the need to encroach. The effective driveway widths can be increased by providing larger curb return radii, angling the driveway, and providing an offset or taper. The latter provides a deceleration area and allows higher entry speeds. Angled driveways with curb returns of 30 to 50 feet, combined with a deceleration area or a taper, will be very suitable for strategic arterials in lieu of closing a driveway.

(3) Driveways should have smooth vertical profiles which will not generate too many g-forces at the design speed. Irregular and rough profiles inhibit entering and exiting speeds and make maneuvering more difficult. The vertical profile rate-of-grade-change requirements needed to afford comfortable driving speeds are much less than the maximum rates (breakover rates) allowable to provide

sufficient clearance between the vehicle underbody and the driveway surface.

(4) *Where direct access to property across the arterial median is permitted,* provisions for two driveways with limited turns is preferable to a single two-way driveway. This arrangement should be channelized with curbs for easy driver orientation. This arrangement eliminates a traffic weave between the entering traffic and exiting traffic that crosses the median. An angular layout makes the movements easier. This layout is shown in Figure 7.5.

(5) Two one-way driveways are preferable to one the single two-way driveway *where direct access to property across the arterial median is prohibited.* This arrangement should be channelized with curbs for easy driver orientation. For this technique to be successful, site layout and signing should very clearly indicate the correct usage. The right-turn entering-traffic driveway should be located upstream from the exiting driveway. This layout is shown in Figure 7.6.

(6) Sight distance requirements at driveways are usually considered the same as the *stopping* sight distances recommended for an appropriate design speed. This issue is discussed in Chapter 4. It is pointed out that an element of stopping sight distance was driver reaction time, which may be related to the *driver's expectancy* in anticipating a stop. If the expectancy is high, it is argued that the reaction time should be reduced to 1.5 seconds, and if it is low, it should be 2.5 seconds (Refs 48 and 83). If driveways can constitute an unexpected event to drivers using the arterial, sight distances corresponding to the low expectancy brake reaction time of 2.5 seconds given in Table 5.1 should be used: for example, a sight distance of 400 to 475 feet for a design speed of 50 mph. Making sight distances compatible with the design speed may require only the removal of signs or shrubs but may also require the relocation or closing of a driveway. In cases where the addition of new driveways is necessary, sight distance can be regulated and enforced during the permit authorization stage.

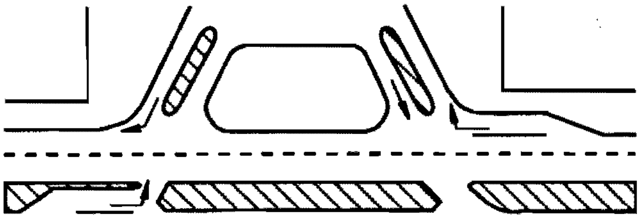


Figure 7.5 Angled two-way driveways with limited turns (Source: Ref 83)

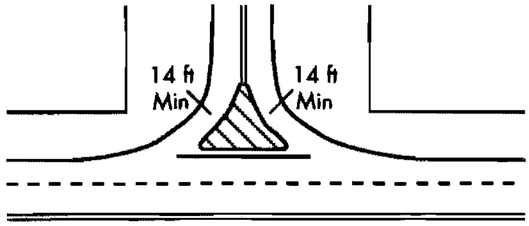


Figure 7.6 Driveway channelizing island to prevent left-turn egress and ingress maneuvers (Source: Ref 83)

(7) Providing an auxiliary lane adjacent to the arterial through-lane will do much to enhance driver comfort and safety when entering and exiting driveways. The auxiliary lane affords additional driving space and allows more time for drivers to detect and to maneuver a vehicle into a driveway. Similarly, the auxiliary lane provides driving space which allows motorists, upon leaving a driveway, to spot an acceptable gap in the arterial traffic stream and to maneuver a vehicle into the stream. In any case, the unobstructed sight distance is usually not afforded, in practice, at driveways and cross streets because visibility is often obscured by the presence of other vehicles ahead and to the side. A driver's first priority in pursuing driving safety should be to observe the vehicle ahead regardless of the sight distance afforded to the next intersection or approaching driveway. It is doubtful if the stopping sight distance requirements are cost-effective when applied to the sighting of lateral events. However, the need for additional lateral sight distance may also support the argument for providing auxiliary lanes along strategic arterials.

(8) Driveways should be paved in order to encourage adequate operating speeds. Vehicles which have to stop or slow or change paths to negotiate potholes or standing water hinder traffic operations. Paving of driveways is normal practice in most cities and should require little additional enforcement, as its application is also preferred by land owners and developers. It should nevertheless be mandatory along strategic arterials. Access management also requires that driveways be maintained over time. The permitting process may require a performance bond from the property owner. The performance bond is to ensure that the driveway is maintained in good order and that its physical condition does not inhibit traffic operations.

(9) If sidewalks are to be provided, they should be set back from the curb line at least 10 feet, or more if there is sufficient right-of-way. The greater lateral clearance gives pedestrians more perception time to see turning vehicles, and the driveway crossing distance is reduced away from the curb line. Intensive pedestrian activity along strategic arterials should be discouraged. Pedestrian activity competes with vehicular activity at intersections and driveways, and should not be allowed to control vehicular operations. Pedestrian grade separations should be provided wherever necessary to reduce the impact of pedestrian activity so that it will not limit traffic operations.

(5) Internal Planning for Traffic Circulation

Proper design and operation of property development is directed at preventing spillover of traffic conflicts that occur inside property abutting a strategic arterial. Lack of internal storage and circulation facilities can create and extend queues into the arterial.

Internal design must facilitate the distribution of vehicles by providing clearly defined circulation facilities. Internal circulation should be designed to minimize the interference between entering and crossing vehicles or at least provide sufficient storage so that queuing entering vehicles will not back into the arterial. Space is needed for vehicles that are searching or waiting for parking spaces or picking up or discharging passengers and cargo. Circulation can be improved if the property interests will participate in the cost of additional acceleration and deceleration lanes adjacent to driveways. Enlarged radii for driveway entrance and exit curb returns may require that additional rights-of-way be set aside for this purpose by the property owner. A well-designed internal circulation system should not cause circulating traffic to re-enter the arterial in order to reach another part of the development or to search for parking space. Although increasing the number of driveways onto an arterial is counter to the goals set for strategic arterials, adding an access point to ease internal circulation problems affecting arterial operations may be considered.

Requiring property users to furnish and operate internal operation facilities will reduce the probability that private traffic problems will become public problems. The approval of access and driveway permits should be contingent upon the property user's provision of a satisfactory traffic-handling plan. Local regulation of internal design may provide adequate standards but will need to be enforced for properties that front on strategic arterials as part of the process of designating strategic arterials. Glennon et al (Ref 83) and Stover and Koepke (Ref 48) extensively cover guidelines for site layout from the perspective of traffic flow and circulation.

(6) The Special Case of Adapting One-Way Pairs to Provide Strategic Arterial Street Service

Some aspects of one-way street operations have been covered previously. As far as access management is concerned, one-way arterial street operations eliminate left-turn conflicts at all driveways and intersections and may, from the perspective of indirectness of access and community acceptability, be much more preferable to left-turn provisions from and within medians along conventional two-way divided streets.

CHAPTER 8. TRANSIT OPERATIONS AND OTHER STREET USES

OVERVIEW OF TRANSIT OPERATIONS

Buses are the most common mode of transit on public streets. Any improvements in the quality of the street system can also improve transit operations. Similarly, the availability of strategic arterial streets for bus operation has the potential to significantly improve transit service. Strategic arterial streets afford a better opportunity for transit operators to improve express service and cross-town operations. Transit operations can be further improved by special facilities incorporated into the design of strategic arterial streets. These special facilities can also mitigate conflicts between buses and other vehicles.

Conflicts

The operation of buses along public streets may conflict with the use of these streets by other vehicles. The principal reasons for this conflict are:

(1) Slow-moving buses make frequent stops. Bus acceleration capabilities are less than those of passenger cars, which may cause additional delays at intersections and along ascending grades. The number of buses present in the traffic stream at any hour corresponds to the hourly demand for commuting service. Unfortunately, the peak hourly flows for buses and those for other vehicles happen to coincide.
(2) Buses which are stopped at bus stops may block lanes temporarily. Even if bus turnouts are provided, buses tend to enter into and exit from these at very low speeds.
(3) Streets served by transit tend to generate pedestrian activity within the right-of-way. Increased pedestrian activity may result in increased foot traffic across streets near bus stops and encourage jaywalking. These activities may inhibit traffic operations if not otherwise accommodated.

Transit operations will benefit from the higher level of traffic service afforded by strategic arterial streets. The challenge will be to design and operate the strategic arterial streets such that bus operations can benefit from the higher quality of traffic service that is available without penalizing other traffic operations.

Bus operations along strategic arterial streets can be enhanced by the following three alternatives, in order of descending preference:

(1) Buses should use strategic arterial streets exclusively for express routes. The loading, unloading, and storage of buses should take place in special areas located well outside the normal right-of-way. These areas could be located on a side street. This will provide the highest level of traffic service to the transit operations and have the least amount of negative influence on traffic operations and safety.
(2) The second alternative is to locate special bus stop areas within the right-of-way of arterial streets but outside the curb lines. These special facilities should be planned, designed, and operated to serve transit operations with a minimal amount of interference to the arterial street traffic. They should be designed to accommodate the loading and unloading of bus passengers and for the storage of buses. These areas should also be planned to accommodate pedestrian traffic and any "kiss-and-ride" traffic (bus passengers driven to and from a terminal in a passenger vehicle) generated by the express bus service. Driveway turnout entrances and exits should be designed to accommodate 15-mph speeds from the auxiliary lane. If an auxiliary lane is not available, adequate deceleration and acceleration lanes should be provided adjacent to the bus turnouts. Consideration should be given to locating pedestrian street-crossing grade separation facilities near the express bus stops to accommodate transit passengers generated by the transit service.
(3) The third and least-desired alternative is to provide bus bays along the strategic arterial.

The bays should be designed such that stopped buses that are loading and unloading passengers will not encroach into the adjacent lane or auxiliary lane. Auxiliary lanes should not be used as stopping areas for loading and unloading buses, as the interference with the adjacent traffic is unacceptable.

OFF-STREET BUS FACILITIES

General

Off-street bus facilities, as considered here, are those that are integrated with developments adjacent to the arterial. Developments, in this regard, can include shopping centers, residential complexes, and business establishments with large numbers of employees situated on large areas of land, as well as other campus-type developments, including actual university and school campuses. Advantages are that

(1) buses can stop well off the arterial street without adversely affecting traffic operations, and
(2) passengers are not in or close to the arterial street right-of-way.

This type of transit integration has been implemented in the past, and a number of guidelines for the integration of transit facilities within developments have currently become available. Other benefits of placing transit within developments include convenience to customers, employees, and residents. Integrating transit facilities within developments depends greatly on the cooperation of developers, landowners, and occupants.

Most objections to the use of transit facilities within developments stem from pavement damage caused by buses and from conflict with pedestrians, but these can be overcome by cooperation between transit authorities, developers, and highway agencies. The formal agreement between developers and the transit authority may include negotiated agreements, cost-sharing arrangements, benefit assessments, and lease or sale of rights, either to or by the transit authority. Developer cooperation can be obtained in a number of ways, including voluntary participation, which is usually based on decreased parking demand, increased accessibility, and customer convenience. Other encouragements can include incentive zoning, through which reduced parking requirements and increased densities are allowed, based on increased transit use.

Bus Bay Location and Design

As mentioned previously, making provisions for bus stop bays is the least-preferred alternative method for accommodating transit operations. If it is necessary to install bays, they should be located and designed to impede traffic operations as little as possible. Some transit operators allow buses to stop and pick up or unload passengers, when so requested, at locations other than at designated bus stops. Such practices are obviously not suited to the concept of strategic arterial streets and should be strictly prohibited.

Location

There are three possible locations, in relation to street and driveway intersections, for installing bus stops. These locations are discussed in NCHRP Report 155: *Bus Use of Highways — Planning and Design Guidelines* (Ref 105). The locations are far-side, near-side, and mid-block; the advantages and disadvantages of each are listed below.

A. Far-Side Advantages

(1) Conflicts between right-turning vehicles and stopped buses are reduced.
(2) The curb lane at the intersection approach is available for other traffic.
(3) Pedestrian traffic crosses behind the bus.
(4) Passenger waiting and boarding takes place away from the street corner in a less crowded area of the sidewalk.
(5) The required maneuvering distance for the bus to enter or leave the traffic stream is usually shorter.
(6) Interruption of the traffic stream by the traffic signal makes gaps available for the bus to reenter the continuing lanes.

The latter point is of importance to strategic arterial streets because higher traffic speeds and less dense platoons will inhibit the ease and safety with which buses can return to the traffic stream.

B. Far-Side Disadvantages

(1) A bus standing at the far side of the strategic arterial street intersection can obscure sight distance to the right of a driver in the cross street.
(2) If the bus stop is of insufficient length or is temporarily blocked, overflow will block the cross street.

C. Near-Side Advantages

(1) There is less interference with traffic turning from the cross street.
(2) Passengers can board the bus close to the crosswalk.

D. Near-Side Disadvantages

(1) There is conflict with vehicles turning right into the cross street.
(2) Signs and signals at the intersection may be obscured by a stopped bus.
(3) Sight distance to the left of a driver entering from the cross street may be obstructed.
(4) Buses returning to the through-lanes may frequently be blocked by queues at the intersection.

E. Mid-Block Advantages

(1) Buses interfere less with sight distances to vehicles and pedestrians at mid-block than at intersections.
(2) Interference with traffic operations at intersections is minimized or totally removed.
(3) Passenger activity and aggregation takes place at less crowded areas of the sidewalk.

F. Mid-Block Disadvantages

(1) The total length of the bus stop is increased since joint use of the intersection is not available with an acceleration or deceleration lane.
(2) Walking distances from crosswalks at intersections and for patrons from some cross streets are increased.
(3) Jaywalking may be encouraged; this may be of particular concern on strategic arterial streets, which have relatively high operational speeds.
(4) Acceptable gaps in the traffic stream for buses to reenter the through-lanes are smaller than gaps at intersections.

The near-side location may be the least desirable; however, the optimum location may not be critical, depending upon the frequency of express bus stops. Ordinary transit bus operations along most city streets call for frequent (4 to 8 per mile) stops. Express service should be more on the order of 1 stop per mile or less. The frequency of signalized intersections along strategic arterial streets is also expected to be on the order of 1 per mile or less. If express bus stops are located at every intersection, then the most desirable location would be at the far side of the intersections. The principal advantage of the far-side location at signalized intersections is that gaps in the traffic stream can be created by the signal. The creation of these gaps for bus merges is important in maintaining stable traffic operations. If the arterial street traffic volumes are high and/or the frequency of bus departures is high, slowly accelerating buses trying to merge into the traffic stream can have an unacceptable impact on adjacent intersection traffic operations. If mid-block express stops are desirable, it will be important to provide suitable deceleration and acceleration lanes so that bus movements in and out of the bays will not inhibit traffic operations.

Design and Operation

The critical design features of express bus stops, with respect to strategic arterial streets, are the provisions made for exiting and entering the arterial street traffic stream. Transit buses are limited in acceleration, deceleration, and maneuvering not only by mechanical restraints but by the responsibility to protect the safety of standing passengers. These limitations require speed-change space for the approach to and departure from the bus stop area. There should be sufficient space outside the main traffic lanes so that the maneuvering involved in entering or leaving the bus stop will not impair traffic operations. As discussed previously, an auxiliary lane can provide the necessary space for speed changes, and the turnout angles and radii to the bus bay should afford adequate operating speeds.

The scope of these guidelines does not extend to the interior design of bus stops, which can range in size from a simple bus bay that is 10 to 12 feet wide (Refs 18, 61, and 105) to a large multi-level facility that provides space for the storage of buses, waiting passengers, and "kiss-and-ride" facilities. The allocation of shared rights-of-way and the cost of additional rights-of-way to accommodate transit facilities must be negotiated with the transit authority. These issues are also beyond the scope of this study. The design of strategic arterial streets should focus on getting buses off and on the arterial street as expeditiously as is feasible.

School Bus Operations

A special case of transit operation is that of school bus operations. As with city bus operations, school bus operations tend to occur simultaneously with the peak demand for roadway capacity. The usual requirement to prohibit overtaking a school bus while it is loading or unloading, whether or not lanes to the left of the bus are available, drastically adds to the negative effect on traffic operations.

Temporary speed limits of 20 mph or less are usually used in the vicinity of schools. These low speeds are usually applied during the morning peak traffic time and could severely restrict arterial street traffic. The presence of schools should be considered when arterial streets are being evaluated for conversion to strategic arterial streets, while alternative accommodation for loading and unloading school buses must be made. Alternatives might include loading strictly on school property and designating loading locations on other streets. Pedestrian grade separations, combined with measures to encourage and enforce their usage on strategic arterial streets, may negate the need for special speed zones.

PARKING

Strategic arterial streets, by definition, are planned primarily to enhance mobility and secondarily to provide direct land access. This definition does *not* allow for on-street parking. Good strategic arterial street design does, however, mandate provisions for auxiliary lanes and adequate driveway design to accommodate *off-street* parking. In selecting existing streets for conversion into strategic arterial streets, some consideration should be given to the *on-street* parking that may exist. The feasibility of removing on-street parking along an existing street as a *condition* of conversion to a strategic arterial street may be a decisive factor in the selection process. The following are the principal effects of on-street parking on traffic operation.

(1) Parallel parking effectively removes from the available right-of-way private vehicle storage space, which could potentially be used to accommodate moving traffic or used for landscaping.

(2) Parallel parking requires a driver to decelerate in a traffic lane, reverse direction, and turn in an S-curve. This maneuver can block the traffic lane. Similarly, the maneuver to re-enter traffic can also cause lane blockage (Ref 109).

(3) The lane adjacent to the parking lane can be blocked by a driver waiting for a space being vacated or by a driver who is allowing another to re-enter traffic.

(4) The presence of parked vehicles adjacent to a traffic lane may create an additional driving hazard if vehicle doors are opened toward the traffic lane. A driver's perception of a safe speed will be influenced by the presence of parked vehicles and the attendant possibility of a door opening and a person emerging into the traffic lane.

(5) The availability of on-street parking may attract pedestrians, which adds the possibility of jay-walking violations. This increases vehicle-pedestrian conflicts and thus influences the standards of safety of the facility. This will also affect a driver's perception of safe speed.

(6) Hasty lane changes and mid-block U-turns are also associated with on-street parking.

The preceding list of effects associated with on-street parking only confirms a policy to prohibit on-street parking along strategic arterial streets.

There are also data relating to the effect of parking on traffic safety. In addition to inhibiting traffic operations, on-street parking increases the accident rate, which in turn restricts the reliability of traffic operations. From a 1967 study, which covered 32 cities and a total of approximately 9,500 accidents, it was concluded that about 18 percent of all accidents involved parking either directly or indirectly and that 90 percent of parking-related accidents were the direct result of parking activity. For almost 94 percent of the parking accidents, the vehicles were legally parked, and the severity, in terms of property damage and fatalities, of parking accidents was relatively low (Ref 112). Another study analyzed previously published research and statistics accumulated from 10 cities covering 170 miles of streets; it was concluded that parking-related mid-block accidents accounted for 49 percent of all accidents on major streets, 68 percent on collector streets, and 72 percent along local streets. The study also showed that increased parking turnover and pedestrian activity resulted in higher accident rates, and that the level of use, rather than the parking configuration (e.g., parallel or angled), was strongly related to mid-block accident rates (Ref 113).

In principle, better use can be made of the area available for on-street parking by using such space for traffic lanes or auxiliary lanes, commensurate with the emphasis placed on the mobility function of strategic arterial streets. It can be argued that private interests can always provide their own parking facilities, whereas they cannot provide personal facilities for mobility, which is, of necessity, a public function. Considering the overall difficulty in acquiring street right-of-way, it seems the better judgment to use public rights-of-way for mobility purposes.

Restricting on-street parking may not be possible in all locations. An existing street which has on-street parking and traffic-dependent businesses but does not have the potential to develop off-street parking may not be a good candidate street for conversion to a strategic arterial. Some innovations may also be necessary to solve this problem, such as the provision of public parking lots as part of the highway scheme. In the case of new developments fronting onto or in the close vicinity of a strategic arterial, development requirements should include adequate on-site parking and circulation areas.

Finally, there will always be the temptation to restrict parking *only* during peak periods of traffic flow. Such a policy may increase illegal parking outside of the restricted hours. Even a few illegally parked vehicles in an auxiliary lane can significantly nullify its effectiveness. The lack of effective parking enforcement may also send a message to potential consumers of strategic arterial street services that the service may not be delivered as promised.

ON-STREET LOADING

In assessing the suitability of candidate streets for conversion to strategic arterial streets, the presence of on-street loading of goods may be an important factor. On-street loading of goods, also referred to as on-street pickup and delivery (P.U.D.), is more commonly found on streets in central business areas of cities. On-street loading may also take place on streets in commercial areas which are being considered for conversion to strategic arterial streets, and, as it can have a very significant impact on traffic operations, some discussion is appropriate.

Like that of bus stops and on-street parking, the effect of on-street loading is to block traffic lanes. In comparison, however, the case of on-street loading lane blockage is measured in minutes and hours rather than fractions of a minute. In practice, such activity may affect more than one lane, depending on the size of the vehicle and the type of goods and method of loading. The presence of workers on or close to the riding surface and the obstruction of sight distance will affect safety of traffic operations and the perception of safe speed by the drivers of passing vehicles.

The negative impact of on-street loading is not compatible with operations expected of any principal arterial, and demand for such activity needs to be considered when choosing and developing strategic arterial streets. In the extreme case, demand for on-street loading, and the absence of alternative loading methods, can be on a level that indicates against the feasibility of establishing a strategic arterial street in a given location. This is most likely to be the case where there are older retail establishments along higher density strip developments, because modern zoning and land-use approvals for properties fronting major streets usually include requirements that restrict loading to the property boundaries. Land use of whatever type is not eternal, particularly that having manufacturing and commercial characteristics, and it may be possible to negotiate a limited-life, on-street-loading variance with the owners of the affected property. Such an arrangement might be cost-effective if the life interest for on-street loading expired before the traffic demand on the strategic arterial street becomes critical. The solution to on-street loading problems, with respect to design and operations, is to isolate these activities by providing a frontage road with suitable connections to the strategic arterial.

CHAPTER 9. PEDESTRIAN ACTIVITY

INTRODUCTION

It is not anticipated that strategic arterial streets will ever serve as important pedestrian corridors. This should not be surprising, since only a tiny fraction of trips taken in American cities, unless for recreation, are solely pedestrian-modal trips. However, virtually all automobile trips end with or start with a pedestrian trip to or from a parking place and rarely exceed 0.25 mile in length. Nevertheless, in any urban area there are places where pedestrians congregate, and it will be difficult to find a strategic arterial street location that does not pass through, or at least near, these places. Where pedestrian activity is intense, and the potential for modal conflict is likely, consideration should be given to avoid the conflict or to provide facilities needed to resolve or mitigate the conflict.

The effect of pedestrian activity on traffic operations on urban streets is usually the most severe at intersections: intersections are usually the place where vehicles and pedestrians aggregate and where each mode competes with the other for a share of the same time and space. Pedestrian street-crossing movements in the mid-block area, although much less frequent than at intersections, can have an effect on traffic operations. Jaywalking, which, in addition to being an unhealthy practice, has an adverse effect on traffic operations, is most likely to occur at mid-block. Any combination of pedestrian trip demands and street design features that might encourage jaywalking should be investigated and resolved.

The usual conflict between pedestrian and vehicular traffic occurs when both types confront a green signal indication and the pedestrian wishes to go straight ahead but the driver of the vehicle wishes to turn right. According to the normal rules-of-the-road, pedestrians have the right-of-way. Under these circumstances the driver of the vehicle must yield, which can cause queuing and delay in the traffic stream. If the vehicle and the pedestrian are going in the same direction, there is no conflict. Pedestrians also inhibit right-turn-on-red movements. Once a pedestrian nears the far side of the cross street, there may be a conflict with the driver who is first in the queue and wishes to turn right on a red light but is restrained because of the presence of a pedestrian. Consequently, delay may then be incurred by the driver waiting for another acceptable gap in the crossing traffic stream.

In practice it has been found that, in areas of high pedestrian activity, the effect of pedestrians may be more pronounced than that indicated by traffic simulation models. It has been observed that pedestrian submissiveness to the discipline of traffic signals may be a great deal less than it is for drivers. The presence of pedestrians, silhouetted by a green light, in the active traffic lanes will affect a driver's perception of safe speed and, consequently, will adversely affect the free-flow speeds and reduce the quality of traffic service.

If the strategic arterial street concept is ever to be realized, it is clear that provisions should be made to accommodate pedestrian activity in a way that minimizes its effect on traffic operations. Streets that accommodate intense pedestrian activity, and that have frequent vehicle-pedestrian conflicts, may not be suitable for designation as strategic arterial streets. Pedestrian safety (provision for and protection of pedestrians) is often an emotional and political issue. It is also expected that the role played by pedestrians in the planning of a strategic arterial street will be very site-specific. However, there is much that can be done to cope with pedestrian demands without having to sacrifice the operational integrity of the strategic arterial. At best, pedestrian activities can be completely removed from competition with vehicular traffic by providing grade-separation facilities. Excellent examples of this can be seen in some of the larger cities, where extensive systems of underground pedestrian passages interconnected with overhead bridges have been provided throughout the central business districts. These facilities not only separate the different modes of travel but also provide a more attractive environment for walking.

EFFECT ON STRATEGIC ARTERIAL STREET LOCATION

Pedestrian activity is one of several factors to be considered in selecting a street to be part of a strategic arterial street system. There are streets which serve areas of intense pedestrian activity. Examples of such areas are schools, special events centers, and large employment centers. Any activity center where large numbers of people congregate is a potential source of intense pedestrian activity. This is especially true if the parking facilities supporting the activity center are separated from the center by a public street.

Strategic arterial streets do not lend themselves to accommodating pedestrian movements without conflict unless special facilities are provided to preclude such conflict. If a street is converted to a strategic arterial, physical conflicts between pedestrians and vehicles can be precluded by careful planning and design. The resulting environment may, however, be unpleasant for pedestrians because of increased traffic volumes and travel speeds. Nevertheless, even a street's ambient environment can be enhanced if sufficient right-of-way is available for installing landscaping and other pedestrian amenities. Consequently, in selecting candidate streets for a strategic arterial street system, consideration should be given to potential pedestrian problems.

PROVIDING FOR PEDESTRIANS

Pedestrians Within the Right-of-Way

The minimum recommended right-of-way width provides 15 feet between the outside edge of the roadway (including the auxiliary lane) and the right-of-way line. This width should be sufficient to provide a 10-foot clearance from the edge of the roadway to a 4-foot-wide sidewalk 1 foot from the property line. Where intense pedestrian activity is encountered, special site-specific planning is required. The owners or managers of conflicting pedestrian traffic generators should be consulted and negotiations to plan and design the overall public and private facilities for the safety and convenience of all concerned should be initiated. The planning and design of such facilities is beyond the scope of these guidelines.

At-grade pedestrian crossings on strategic arterial streets may be sanctioned at signalized intersections if the signal phasing can be arranged to accommodate pedestrian safety without compromising traffic operations along the arterial streets. Preferential treatment for traffic on a strategic arterial street likewise apportions a larger share of the green-time to the arterial street at a signalized intersection. This preference reduces available walk-time for pedestrians crossing the arterial street at signalized intersections. Ideally, on strategic arterial streets, signalized intersections will be spaced well apart, very likely in excess of 1 mile. In addition, grade separations may be located every 1 or 2 miles, and they will also provide opportunities for pedestrian crossings. However, these spacings, and the possibility that some intersections cannot be adapted to pedestrian crossings of the strategic arterial streets, may result in a need for pedestrian crossings at locations between signalized intersections.

There are special circumstances involving the spacing and operation of an interconnected traffic signal system which will afford an extra long green phase at a signal located midway between intersections. If this opportunity occurs, it is possible to provide about twice as much green-time for pedestrian crossings at mid-intersection as at an intersection. In this case, a mid-intersection location might permit the installation of an at-grade pedestrian crossing which otherwise could not be tolerated at an intersection.

Where grade-separated interchanges are provided, at-grade pedestrian crossings can be easily accommodated, because crossing pedestrians will be in conflict with turning traffic only between the strategic arterial street and the cross street. If grade separations only (without interchanges) are provided at streets and railroads, they can also function as pedestrian grade separations with only minor modifications.

In general, the safety of pedestrians on the rights-of-way and in intersections is enhanced by the use of lighting, refuge islands, barriers, and signals. Pedestrian safety can also be improved by providing sidewalks, as they encourage pedestrians not to use the roadway, and by providing more opportunities to cross the roadway at designated locations (Refs 18 and 120).

Pedestrian Crossings at Signalized Intersections

Signalized intersections on strategic arterial streets may or may not prove suitable for pedestrian crossings, depending on the signal plan used and the roadway widths. Where a two-way street with a median and two or more lanes per direction is under consideration and a high $(g+y)/c$ ratio is assigned to the arterial street approach, provision needs to be made for pedestrians to find shelter on the median and to use two cycles to cross the arterial. The need for shelter increases as the widths of the approaches to the intersection increase. A conflict in this regard is the possibility that narrow no-left-turn medians will be used for strategic arterial streets, but this lack of space can be solved by widening the medians at intersections to provide pedestrian havens.

Pedestrian Grade Separations

High-volume, high-speed urban roads are prime locations for installing pedestrian grade separations. Crossing over or under a street by way of a grade separation often increases a pedestrian's walking time and effort, which may encourage crossings at grade. It has been found that saving time is the stimulus that drives a pedestrian to use a grade separation facility rather than crossing at grade (Ref 121). This time differential may have to be artificially created by installing a barrier such that the time path through the grade separation facility is less than that through the nearest at-grade crossing (Refs 18 and 122). The provision of the traditional New Jersey concrete median barrier supplemented by a headlight glare screen can function effectively as a barricade. The location of a pedestrian grade-separation facility can also make use of the facility more appealing. It has been found that pedestrian grade separations are most effective when integrated into land development, built in a natural and direct link between activity centers, and planned for in the overall highway design (Refs 95 and 121).

When highway structures cross over pedestrian pathways, the pathways are referred to as pedestrian underpasses. Conversely, structures carrying pedestrians over highways are called pedestrian overpasses. Underpasses, especially in a retrofit situation, are more difficult to construct and are usually more costly, and drainage maintenance can be a problem. Underpasses may suggest a more menacing environment to pedestrians if not adequately lighted, cleaned, and maintained. The security, real or perceived, of pedestrians using an underpass is an important consideration in design and location. Although lighting of overpasses is desirable, security considerations make lighting of underpasses essential. Overpasses are more visible from a distance, making pedestrians more aware of the presence of an alternative to crossing at grade (Refs 18 and 123). On the negative side is the consideration that overpass structures add to the visual clutter on some roadways. Another problem sometimes encountered with overpass structures involves miscreants who drop objects onto the traffic passing under the structure. Although there is no socially acceptable solution to this type of behavior, the installation of screens and barriers according to some AASHTO guidelines (Refs 18 and 124) should alleviate this problem.

All pedestrian facilities should be accessible to handicapped persons. AASHTO (Ref 18) offers some general guidelines to facilitate handicapped access, including grades, spacing, and sizes of landings. The additional space required to include sloping ramps and landings needs to be considered in selecting locations for pedestrian grade separations. It is apparent that pedestrian grade-separation facilities will have more application along strategic arterial streets than on conventional highway facilities because there will be fewer opportunities for installing at-grade pedestrian crossings. The operational requirements for strategic arterial streets are such that the space-time frame available for pedestrian crossings will be limited.

The demand for pedestrian crossing trips will change as new highway or street facilities interact with and transform land use. Where these trips are proscribed or inhibited, the demand for pedestrian trips will diminish. Even if grade-separation facilities are provided to accommodate the demand, subsequent land use changes may cause this demand to diminish. There are urban pedestrian-freeway grade-separation structures that were installed to accommodate historical foot trip patterns which afterwards became little used. This outcome is not uncommon as subsequent land use changes, influenced by the presence of the freeway, also change the demand and direction of pedestrian trips. Unless they are both a product of and a part of some larger scheme of planned development, pedestrian trip demands are likely to prove transitory and unpredictable.

CHAPTER 10. IMPLEMENTATION ISSUES

INTRODUCTION

Implementing a strategic arterial street system will require a systems plan recommending specific routes and locations and instituting measures to finance and construct specific improvements. The first action in planning will be to identify, for inclusion in the system, specific routes as candidate strategic arterial streets. This inclusion is desirable in order to encourage the application of appropriate design and traffic control standards along the routes, and will discourage actions that would complicate future arterial street improvements. Identification of routes is also important to private property interests fronting these routes inasmuch as strategic arterial street improvements may affect land use. The installation of a strategic arterial street system can be implemented only as a result of political action. Such action is necessary to obtain the resources and authority for planning, constructing, and managing the system. This chapter addresses the role of authority in the project, as well as the sources and implications of community response.

SELECTING LOCATIONS FOR STRATEGIC ARTERIAL STREETS

There are general conditions which may favor strategic arterial street implementation. These conditions along the candidate route involve the type and intensity of abutting land use, the patterns and intensity of arterial street and crossing traffic flow, and the physical characteristics of the street. Selecting a route is analogous to finding and stringing together all the segments within a given corridor where conditions are favorable for supporting a strategic arterial street. In order to provide route continuity, it is likely that segments whose conditions are not favorable will have to be included in the string. The planner must attempt to find routes that are as favorable as possible and must accommodate unfavorable conditions through design and negotiation. Below are some general conditions which affect locations.

(1) The potential for acquiring adequate rights-of-way is probably the key factor in determining whether or not a particular street route can be upgraded to a strategic arterial street. Right-of-way needs should include the additional areas of rights-of-way essential to installing grade-separated interchanges, U-turns, jug-handle turns, and public transit facilities. The highest potential for acquiring rights-of-way is where the existing dedicated rights-of-way are adequate. The potential is reduced where minimum right-of-way-taking lines would capture expensive real estate improvements or so damage whole property remainders as to cause expensive whole takings. The costs of rights-of-way have to be viewed from the standpoint of the whole system. In order to produce a system that is of uniform quality and free of gaps, it may be necessary to include segments which are relatively expensive because of high right-of-way costs. These segments may not in themselves be cost-effective, and the cost should be averaged with donated or inexpensive takings.

(2) A candidate route should be as long as possible to permit the strategic arterial street to attract trip demands of moderate length (3 to 10 miles) in order to provide an attractive alternate trip path for vehicles using the freeway system. A minimum length of 3 miles is suggested, with 5 miles or longer preferred.

(3) The candidate arterial street should be bounded by predominantly low-density development, with few driveways having direct access to the street. Where undeveloped land is encountered, developers should be encouraged to eliminate frontage access to the strategic arterial street or to plan the use of the property so that driveway access is restricted to a 0.25-mile spacing or greater.

(4) Potential signalized intersections should not occur more frequently than 0.5 mile. If the frequency of potential signalized intersections is greater than two per mile, then plans

should be made to replace some of these intersections with grade-separated interchanges.

(5) The alignment of candidate routes should accommodate horizontal curves of 45- to 50-mph design speed. Similarly, the topography should permit the installation of vertical profiles which will accommodate heavy vehicle operations.

(6) A desirable location to end a strategic arterial street would be at a pair of one-way streets or other facilities having sufficient capacity to handle the strategic arterial street traffic. An example would be a grid of one-way streets servicing the central business district of a large city or major suburban business-commercial development node or terminals associated with a higher-order facility, such as a freeway interchange or frontage road.

(7) One-way street pairs offer opportunities for conversion to strategic arterial street standards. One-way pairs can easily accommodate two-way signal progression which will permit one-way pairs to operate at desirable strategic arterial street speeds. The separation of the pairs voids the need for a concrete median barrier to prohibit left turns from abutting property into the traffic stream. The wide separation of the pairs permits direct left turns without inhibiting traffic.

(8) Streets which pass through areas of high pedestrian activity (i.e., school speed-zones, or commercial strip development of medium or higher density) may be undesirable candidates. Even though segments along a candidate street may appear unattractive because of undesirable land use characteristics, these can be compensated for or controlled by geometric design and the acquisition of access rights. These measures may be expensive but overall they are more cost-effective if the alternative is to omit system segments.

(9) Transit operations need to be considered. Strategic arterial streets should be designed to accommodate express bus service where loading/unloading facilities are physically separated from the arterial street lanes and are accessible only by side streets or by special exit and entrance driveways. Streets being used for local bus service, where on-street loading/unloading is frequent, are not desirable for conversion to strategic arterial streets unless these local services can be moved to another location.

DESIGNATION OF STRATEGIC ARTERIAL STREETS

Adoption of a policy designating strategic arterial streets should be seen as the first very important step in the development of a strategic arterial street system. Similar to the State of Colorado Access Code, such designation should be supported by the necessary legislation, regulation, administrative processes, design standards, and specifications.

Designation of specific facilities in this way will ensure consistent application of design guidelines so that a facility can provide the desired mobility levels. Designation as a strategic arterial street is deemed necessary in order to reduce the effect which political actions very often have on efforts to upgrade urban streets. Designation will clearly communicate to all involved—including highway authorities, public participation groups, political decisionmakers, and road users—an understanding of the required standards and goals. Another aim of the strategic arterial street designation is approval of the design and operating principles for a street or system, rather than consideration of each treatment separately. This can be seen as analogous to practices associated with freeway planning, where the decision is simply whether to build a freeway or not. The basic design characteristic of a freeway is implicit: for example, full control of land access and is provided, all road connections are made through grade-separated ramps.

Initially, regulations supporting the designation may be required in order to clarify the basic characteristics of the proposed strategic arterial streets. Such regulations may be used to clarify

(1) the principle of preferential treatments for strategic arterial streets, in terms of control of access and allocation of signal green-time;

(2) the use of grade separations at some urban street intersections;

(3) implicit highway authority power to prohibit all new driveways where alternative access exists;

(4) the requirement of a driveway permit, or permit review, for new access points and locations where land use changes occur;

(5) authority to require from new developments, through the permit system,
    - high driveway standards, including the use of speed change areas, with widths, curb return radii, number of driveways, and spacing specified;
    - proper paved construction and maintenance of driveways;

  - placement of barriers on fronting boundary lines; and
  - adequate parking and internal circulation area;

(6) authority to undertake construction work on existing driveways to make them conform to the selected standards;
(7) authority to set building lines and require the donation or other transfer of required rights-of-way; and
(8) authority to implement incident response procedures including authority to remove accident vehicles from roadway.

Designating a strategic arterial street and supporting the designation by regulation may be one of the most important elements in determining the success of the project.

AUTHORITY FOR MANAGING STRATEGIC ARTERIAL STREETS

Political issues cover not only public reaction, often reflected in the decision made by officials, but also the interaction between agencies and authorities involved in providing a transportation infrastructure, and include issues such as

(1) agreement on specific standards of design;
(2) authority over the project; and
(3) agreement on relevant issues, where one roadway project traverses areas of several local authorities.

The length and continuity of strategic arterial streets, combined with political subdivisions of urban areas, introduce the problem in which a single strategic arterial street may pass through several city and county jurisdictions. For example, the Beach Boulevard Super Street passes through ten different cities. Conflict, detrimental to the goals set for strategic arterial streets, can occur when

(1) different cities have different design standards;
(2) relatively strict management of land access and closing of driveways and cross streets may not find the same level of support with all local authorities; and
(3) a strategic arterial street may be seen as an intrusion by certain communities, which realize that the arterial streets are aimed at serving longer-distance trips and may not necessarily provide direct benefit to the specific smaller community, while at the same time introducing high-speed, high-volume traffic.

These problems can be cumbersome, but a single authority should take a leadership role in the whole project and be responsible for negotiating with local communities, financing, planning, and construction, as well as the operational management of the strategic arterial street. In the case of the Super Streets project in Orange County, California, it was the Orange County Transportation Commission (OCTC) that took the leading role, despite the fact that some of the selected streets were owned and operated by the California Department of Transportation. In other locations it may well be the State which will be best suited to establish strategic arterial streets. There are advantages in having the state play the leading role.

(1) A network of strategic arterial streets will most likely cross city and county boundaries; e.g., the proposed Strategic Arterial Street System for Harris County, Texas, which comprises 481 miles inside the county but, to provide route continuity, also needs 120 miles outside the county (Ref 14). The next higher highway authority will have at least some jurisdiction over the whole area.
(2) State highway departments are further removed from local political issues and will be more inclined to make longer-term decisions in the interest of the community at large.
(3) States carry more authority and may be more successful in establishing, maintaining, and enforcing high standards of geometric design and access management and may be more successful in obtaining right-of-way required to establish strategic arterial streets.
(4) One of the aims for strategic arterial streets is to relieve urban freeway congestion and to decrease the need for more freeway construction. As urban freeways are mostly managed and funded by states, states will have a direct interest in the success or failure of strategic arterial streets.
(5) The state's experience, its expertise, and its organization can be used to oversee community input and participation in the planning process.

One final suggestion is that State Highway authorities should reexamine their commitments and responsibilities in dealing with urban traffic problems. This suggestion is a consequence of recognizing that the state may be the most capable and resourceful agency—and may be the only agency—having a sufficient scope of authority to contract and negotiate with various combinations of cities and counties.

COMMUNITY RESPONSE

There will be community reaction to the implementation of strategic arterial streets. Political and social factors play an important role in the process of implementing high-level improvements to arterial streets and can directly determine whether or not the project will be implemented in accordance with desired standards. If planners and engineers are aware of the sources and bases of objections, suitable courses of action will become clearer. One course of action will be to avoid establishing strategic arterial streets in areas which are so sensitive that the roadway improvements are unlikely to be accepted. On the other hand, there are actions that have been shown to generate greater community support. Responses may come from residential groups, local governments, developers, and existing businesses.

Residential groups are usually concerned with the effect of higher-volume, higher-speed traffic on neighborhoods. Plans that are perceived to lead to increases in through-traffic (considered intrusive, annoying, and unsafe) will meet with objection. Residents may also oppose structures considered to be visually and physically intrusive, such as grade separations and median barriers. Safety of travel, including the perceived safety of pedestrians and especially that of children, is usually high on the agenda of neighborhood groups and very often becomes an emotional and political issue. Residents may object to the removal or reduction of available on-street parking and to roadway treatments that would lead to more circuitous travel routes. Ultimately, objections to the increase of taxes to finance projects may arise.

Residential groups can and do exert pressure on local elected officials. Local officials may also fail to see the benefits of proposed highway improvements and may question the benefits to their own community. The support of local authorities will, however, be essential for the success of strategic arterial streets. Local government may also be concerned about travel time and navigation of emergency vehicles (Ref 92).

Developers and retailers may also be concerned with some of the above-mentioned issues. As far as the treatments discussed in previous chapters are concerned, the main area of attention is the restriction of property access. Most opposition is likely to come from commercial land uses which are dependent upon attracting passing traffic. The business sector also may be able to summon political influence, which can affect the level of access control eventually implemented, irrespective of the legal basis for the actions.

Areas of major community concern should be considered during the selection of candidate strategic arterial streets and treatments to be implemented. Approval of a project can be obtained by public participation in the planning process and by directing attention to the benefits of the proposals.

Community participation can play an important role during the planning stages, including the designation of the facility. Commensurate with the designation of strategic arterial streets will be the acceptance of the principles of the project, including all necessary improvements, rather than seeking separate approval for each small individual improvement. Regulations accompanying the designation may be of value in enforcing the application of specific roadway improvements, despite some objections.

Public support can also be obtained by disseminating information about the project. For both the Colorado Access Control Demonstration project and the Orange County Super Street project, information was mailed directly to interested persons, and early public meetings were held. Even compulsory public hearings can be used as a forum for disseminating information.

Access management can be beneficial to businesses and other developments located along or near arterial streets. If use of the arterial street or driveways located on it becomes hazardous or frustrating, persons may be less inclined to use that arterial street. Developers are becoming increasingly aware that arterial street traffic-carrying capabilities control the long-term success of their developments and are increasingly willing to cooperate in the solution of access and traffic problems.

Although the impact of access control on businesses has been extensively researched, there are no clear answers. The issue is complicated by normal cycles in the economy: some highway improvements restrict access but increase safety, provide greater mobility, and attract larger traffic volumes, which in turn stimulate economic activity. NCHRP Report 93 (Ref 53) presents a number of specific studies on the question of non-user impacts of highway improvements. A recent study, which included a literature review and a survey of transportation and traffic engineers in state and city governments, found no documented evidence to substantiate claims that raised medians cause business failures, except when the business was oriented to drive-up patronage (Ref 92). Patronage of business may decrease during and shortly after the construction period but tends to improve later. Admittedly, this is of little consolation to a business operator faced with a period of reduced sales and losses, but knowledge of general findings may help officials identify genuine concerns.

Stressing the safety benefits of improvements may play an important role in obtaining support. Safety is usually an issue of immediate concern, and may be more accepted than other long-term improvements. Furthermore, public objections are often based on misconceptions of the proposed project. Experience with similar treatments may help dispel fears.

As indicated by the discussion of access control in Colorado, the support and participation of city, county, and state officials is essential. Participation by these groups can be obtained through joint project teams, the dissemination of information through presentations, and placing special emphasis on the need for all to understand and agree with the goals of the project. Local elected officials must be involved in such efforts. Local support may also come from the realization that major arterial streets are essential to high-quality transportation and continued growth.

CHAPTER 11. FUTURE DIRECTIONS

INTRODUCTION

This chapter introduces some aspects of the operation and application of strategic arterial streets that have not been covered elsewhere but will become important only when strategic arterial streets have been placed into operation. The principal issues to be addressed are the continual management and enforcement of traffic operations and access controls along strategic arterial streets.

MANAGING STRATEGIC ARTERIAL STREETS

The guidelines offered in the preceding chapters concentrate on the physical appearance of strategic arterial streets, including treatment of geometry, intersections, and management of access. Once arterial streets have been implemented as suggested herein, it will be important that measures be taken to ensure fidelity to the operational goals established for strategic arterial streets. Management measures needed to maintain continual reliability of the service provided by strategic arterial streets are briefly discussed. The major emphasis is directed toward day-to-day management of specific facilities and includes monitoring and controlling traffic operations, incident management, and enforcement.

Monitoring Operations

During the course of this study, the literature reviews and consultations with traffic operations managers revealed a severe lack of operational data concerning urban arterial streets. In contrast, considerable data are available concerning freeway operations. Considering the notion, referred to in preceding chapters, that some of the practices used on freeway operations should be extended to strategic arterial streets, it is recommended that regular monitoring of strategic arterial street operations be undertaken. On a day-to-day basis it can be an important supplement to incident management, discussed below, and in the long run can be useful in improving incident-free traffic movements. The level of operations can be estimated by measuring the average travel speed, number of stops, or stopped time in chase-car surveys, for example, at different times of day. Traffic counts, which are generally the most readily obtainable data concerning traffic operations, can be used to assess whether or not the operational goals set for strategic arterial streets are being met or whether remedial action is required. Remedial action can include any of the concepts discussed in this study. Specific actions might range from simple and less costly exercises, such as enforcing regulations (e.g., parking violations) or retiming signals, to more costly measures, such as the installation of a grade separation.

Incident Management

Incident management applied to urban freeways is receiving increasing attention. This has resulted from recognition of the importance of freeways to highway users and the adverse effects of incidents on freeway operations. In the Los Angeles area, CalTrans reported that users' time lost because of congestion caused by freeway incidents was greater than the time lost because of recurrent congestion.

Incidents on freeways generally are well publicized by the media and/or are reported by passing and involved motorists, and the police are asked to clear the incident as soon as possible. Unfortunately, incidents on other urban facilities, including urban arterial streets, are generally not afforded the same attention. Physical response to incidents on arterial streets is usually left to local law enforcement officers. Depending on the size of the urban area, local police may have a special traffic branch, working in collaboration with the traffic or transportation departments, but, as the title suggests, such teams are primarily involved with law enforcement, and stimulating traffic flow is a secondary goal.

Actions which can be included under incident management involve

(1) creating special incident response teams primarily concerned with responding to and clearing incidents on the strategic arterial street network;
(2) including within desirable legislation, supporting the designation of strategic arterial streets, the authority for law enforcement officers and incident response teams to remove accident-impaired vehicles from the travel lanes; and
(3) creating plans to handle and re-route traffic in the event of a major incident or when special events affect traffic on the strategic arterial street.

It would be desirable, under incident management, to have the plans and means to handle and prevent possible failure of the mechanical and electronic systems controlling traffic signals. Such events are not altogether rare, adding to the possibility that an incident will adversely affect the efficiency of operations on arterial streets. Systems allowing the on-line monitoring of signal functioning can reduce the occurrence and consequences of failure of signal equipment.

Enforcement

The issue of enforcement of the necessary regulations is discussed in previous chapters. Many of the guidelines discussed previously dealt with enforcement of desirable traffic operations by use of geometric design and other physical features, such as the use of solid median barriers to inhibit illegal left turns, thus reducing the demand for continual enforcement. Enforcement as addressed herein refers to human intervention as necessity demands and in this sense includes the day-to-day monitoring of traffic operations and enforcement of both traffic and access control regulations. The enforcement of traffic regulations is considered vital in affording a high level of traffic safety, operations, and reliability of operations, and includes enforcement of

(1) maximum and minimum speed limits,
(2) parking restrictions,
(3) restrictions of on-street loading, and
(4) illegal turns and stopping.

The enforcement of access control regulations will require the cooperation of various agencies, including the city planning department, public works, traffic engineering, law enforcement, public transportation, elected officials, and perhaps public interest groups and the public at large. Enforcement activities will include the following:

(1) access management,
(2) zoning and other land use controls, and
(3) appropriate location of public transportation routes and bus stops.

The enforcement of access controls may well be a very involved and challenging process. It is hoped that once the value of strategic arterial streets is appreciated, enforcement will be recognized as necessary and will be implemented in order to attain the level of productivity and reliability which defines strategic arterial streets.

Managing Traffic Flow Entering Strategic Arterial Streets

Associated with monitoring and managing traffic operations *along* strategic arterial streets is the controlling of traffic *approaching* the arterial streets. Many of the guidelines suggested previously are directed toward traffic operations for the case of non-congested flow: for example, flow conditions where demand does not exceed the absolute capacity of the facility. Unstable traffic flow conditions caused by overextension of the capacity of the facility are characterized by delays and interrupted flow, which are not compatible with ~~the~~ goals of strategic arterial streets. A further step in improving traffic productivity is to consider the management of traffic approaching a strategic arterial street. It is suggested that traffic management techniques similar to those used for managing freeway operations can be used for managing strategic arterial street operations. The ultimate concept of managing strategic arterial street operations envisions that *all* traffic entering a strategic arterial street will pass through a signalized intersection, which in effect is a gate to control or limit traffic input. Whether or not all side streets and driveways would have to be signalized and controlled would depend upon the amount of traffic generated and the time at which it is generated from these side streets and driveways. The operational concept is: when the traffic input into the street (considered as a system) exceeds the output and causes the quality of service to diminish to the lowest acceptable level, then the approaching traffic will be constrained.

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