

***Southwest Region University Transportation Center***

**Congress Avenue Regional Arterial Study:  
Collector - Distributor Lanes**

SWUTC/95/60019-1



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<p>16. Abstract</p> <p>The concept of a collector-distributor lane system as part of a regional arterial street improvement program is introduced. Such a system can improve operational aspects of certain urban arterial streets by provision of a transitional space between through-traffic streams and entering-exiting streams. Facilities for which this concept is most applicable, are arterial streets along which development has occurred that is inconsistent with the arterial street primary function which is, according to the 1990 AASHTO Policy, through travel and major circulation movement. For the comprehensive regional arterial program, as well as the collector-distributor system, the acquisition of additional right-of-way is regarded as cost and/or time prohibitive.</p> <p>The idea of exclusive right-turn lanes along arterials is covered in some detail, and many reports recognize the applicability of right-most lane to separate turning and slower moving vehicles from through traffic.</p> <p>Issues that have potentially significant impacts on design and operation of urban arterials are described, specifically, those that pertain to the design and implementation of collector-distributor lanes.</p> <p>Benefits of converting an existing through-traffic lane into a collector-distributor lane are identified, and criteria for implementation of a collector-distributor lane are described and recommended design standards and procedures are presented.</p>			
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**CONGRESS AVENUE REGIONAL ARTERIAL STUDY:  
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by

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**Research Report SWUTC/95/60019-1**

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## EXECUTIVE SUMMARY

This report is the first of four which document work performed as part of the Southwest Region University Transportation Center (SWRUTC) study "Demonstration of Enhanced Arterial Street Traffic Flow, Reduced Fuel Consumption and User Costs Through Application of Super Street Technology". This study constitutes an effort to demonstrate user benefits through development and application of state-of-the-art traffic engineering technology. Specifically, it is an effort to produce an improvement program for Congress Avenue in Austin, Texas which will upgrade its functional class from "major arterial" street to "regional arterial status" and quantify associated user benefits. One extremely important study component is development of new technology which can solve basic problems encountered during improvement plan preparation.

This report deals with a concept which is new, at least for arterial streets. Collector-distributor lanes have been used on fully controlled access facilities to reduce friction between through traffic flows and entering-exiting flows. Collector-distributor lanes are proposed as a central part of a multi-part system for accomplishing the same function on partially-controlled access regional arterials. The system includes improved driveway geometric standards, strictly controlled left-turn opportunities, and a right side collector-distributor lane, serving as the transitional space between through traffic streams and traffic accessing adjacent property. Design concepts for these elements, development rationale, and potential user benefits are described.



## ABSTRACT

The concept of a collector-distributor lane system, as part of a regional arterial street improvement program is introduced. Such a system can improve operational aspects of certain urban arterial streets by provision of a transitional space between through-traffic streams and entering-exiting streams. Facilities for which this concept is most applicable, are arterial streets along which development has occurred that is inconsistent with the arterial street primary function which, according to the 1990 AASHTO Policy, is through travel and major circulation movement. For the comprehensive regional arterial program, as well as, the collector-distributor system the acquisition of additional right-of-way is regarded as cost, and or, time prohibitive.

A literature review indicates that the concept of collector-distributor roads is addressed only moderately. The idea of exclusive right-turn lanes along arterials is covered in some detail, and many reports recognize the applicability of a right-most lane to separate turning and slower moving vehicles from through traffic. However, it appears that the literature is lacking in any works that specifically address the use of the right-most lane of an arterial in the manner in which this study proposes.

Issues that have potentially significant impacts on design and operation of urban arterials are described along with those that specifically pertain to the design and implementation of collector-distributor lanes. These include channelization, control of access, driveways, weaving areas, and friction between traffic streams.

Finally, potential benefits that can be derived from converting an existing through-traffic lane into a collector-distributor lane are identified. Criteria for implementation of a collector-distributor lane are described and recommended design standards and procedures are presented.



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## CHAPTER 1. INTRODUCTION

With ever increasing traffic demands upon our transportation infrastructure, in particular our urban freeway networks, with growing awareness of environmental degradation, and with limited space and funds to build new freeway lane miles, it is desirable to improve the efficiency and traffic handling capabilities of the existing arterial street system. This study will examine the role of the arterial street in the urban road system and try to determine whether efficiency and traffic carrying capacity can be improved by implementation of what will be referred to as a collector-distributor lane. This lane, in principle, will serve the same purpose that a collector-distributor road serves along a freeway. It will provide a facility that separates higher speed, through-traveling vehicles, from potential conflict with lower speed vehicles, thus reducing inter-vehicle friction and the potential for accidents while increasing speed, capacity, safety, and efficiency.

### OBJECTIVES AND SCOPE OF REPORT

This report will identify several of the more significant factors that affect the operations of an urban arterial street and analyze the operational aspects that can possibly be improved through the implementation of a collector-distributor lane. The situation for which these analyses will be performed, and for which recommendations will be made, is that of an existing arterial street along which development has occurred that is inconsistent with the primary function of an arterial street. In the 1990 AASHTO *A Policy on Geometric Design of Highways and Streets* (Ref. 2), the role of principal urban arterials is described as providing for through travel and major circulation movements within an urbanized area. It describes service to abutting land as being a subordinate role to the above mentioned primary functions. Unfortunately, due to a lack of strict land use control and resulting property access needs, development along arterials, adversely affects traffic operational characteristics. As traffic demands on arterial streets increase, it is desirable to improve, with minimal costs, the operational characteristics. For the situation examined in this study, the acquisition of additional urban right-of-way is regarded as cost prohibitive; therefore, an attempt is made to work with existing conditions so that results can be achieved quickly and at reasonable cost.

Chapter two summarizes significant previously conducted research. It was determined that the concept of collector-distributor roads along freeways is addressed only moderately in the literature. The idea of exclusive right-turn lanes along arterials is covered in some detail, and many

reports recognize the applicability of a right-most lane to separate turning and slower moving vehicles from through traffic. However, it appears that the literature is lacking in any works that specifically address the use of the right-most lane of an arterial in the manner in which this study proposes.

The next task involved consideration of issues that have a potentially significant impact on urban arterial design and operation. The issues addressed in this report are those that are thought to offer a practical means of improving operations while not incurring costs that might essentially outweigh potential benefits. Chapters three and four discuss the significant issues pertaining to the design and implementation of collector-distributor lanes including channelization, control of access, driveways, weaving areas and friction between traffic streams.

Finally, this study evaluates the potential benefits that can be derived from converting an existing through-traffic lane into a collector-distributor lane. The goal of this report is to identify criteria for implementation of a collector-distributor lane and then, based on those criteria, recommend design standards and procedures.

## CHAPTER 2. LITERATURE REVIEW

A review of the literature was performed to determine to what extent, if at all, the topic of collector-distributor lanes had been addressed. The results indicated that the issue of collector-distributor lanes on urban arterial streets had not been directly addressed. It was determined, however, that many issues closely related to this topic had been written about, and much of the research provided results directly applicable to this topic. Therefore, to a degree, this report will be a presentation, in a cohesive and logical fashion, of results from related studies, adapted so as to be appropriate for the proposed application. What follows are brief summaries of the literature which have applicability to this study, divided into groups based on the issues which are addressed.

### ACCESS CONTROL

The first group of works reviewed pertain to the control of access to property adjacent to arterials. Topics included in this category are legal aspects of access control, abutters' rights, right-of-way acquisition, land use, driveway design, and driveway spacing.

Azzeh et. al. (Ref. 1) provides a complementary volume to Glennon et. al. (Ref. 4). The latter study provides an exhaustive variety of cost effective access control techniques which can be implemented to optimize traffic operational efficiency and safety while providing sufficient and suitable access to properties along arterials. The former study reviews the various techniques based on safety, reduction of delay, and cost-to-benefit criteria. Several recommended access control, channelization, and driveway design and spacing techniques have direct applicability to the analysis presented in this report.

Netherton (Ref. 12) traces the historical development and present concept of access control. Included are discussions of legal issues, right-of-way acquisition, abutters' rights, land use and value, and types of highways.

In his study, Mounce (Ref. 11) recommends minimum, typical, and desirable driveway design standards for driveways entering arterial streets using fuel consumption as a measure of effectiveness. A simplistic model was used to illustrate differences in fuel consumption incurred by vehicles forced to decelerate from a given speed by vehicles entering the arterial from driveways of varying levels of design standards. Results are given for a condition of 35 mph arterial speed and indicate that the differences in annual fuel consumption due to varying driveway design standards are negligible for an arterial-driveway hourly volume product of less

than 100,000 vehicles per hour. Between arterial-driveway volume products of 100,000 and 500,000 vehicles per hour, there is significant fuel savings produced by the use of desirable versus minimum standards. Above a 500,000 vehicles per hour arterial-driveway volume product, desirable driveway standards are justified by substantial fuel savings.

Hallam's report on access control policies (Ref. 5) are reviewed and a recommended code is discussed. New guidelines for driveway locations and design are included.

Neuman's *Intersection Channelization Design Guide* (Ref. 13) is a comprehensive guide for the planning and implementation of effective channelization techniques at intersections. A wide spectrum of related issues are addressed including human factors, features contributing to accidents, principles and objectives of channelization, exclusive right-turn lanes, driveway design, and access control.

## **GEOMETRIC DESIGN**

This section describes studies performed to evaluate the effects of geometrics on arterial operations and safety. Also included in this section are several reference manuals which recommend geometric design standards for arterial streets. Topics addressed in these works include sight distances, uniformity of geometric features, design vehicle standards, treatment of curbs and shoulders, and lane widths.

Stefaniak and Wallace (Ref. 19) evaluate collector-distributor roads along a 16 mile section of I-270, between Washington D.C. and Frederick, MD. A literature review done in this paper determined that minimal information was available concerning collector-distributor road design. Operational data was collected from Texas and Illinois to arrive at recommendations for geometric design. Recommendations included 12-foot lane widths for collector-distributor roads with 2 or 3 lanes and a 15-foot lane width for collector-distributor roads consisting of only one lane. Minimum shoulder widths were recommended as 4-foot left and 14-foot right with an absolute minimum of 4 feet.

In Torres' report (Ref. 21), the relationship between travel time and volume is evaluated based on urban arterial sections of varying geometrics and traffic control factors. A set of curves is presented by which travel time-volume relationships can be estimated from knowledge of various known characteristics of the street.

Taylor and McGee (Ref. 20) present a comprehensive summary covering the application of various methods of delineation, delineation material properties, pertinent human factors, and cost effectiveness.

Martin, Newman, and Johnson (Ref. 9) evaluate traffic flow characteristics for several high-standard geometric design features. The study includes collector-distributor roads, auxiliary lanes, and lane drops. Traffic density, measured by vehicles per lane-mile was used as the primary measure of effectiveness. A major finding of this study was that freeways offering greater freedom of choice to drivers have more efficient operation. For example, freeways with auxiliary lanes have greater flexibility, capacity, and efficiency than freeways with a collector road system.

Olson and Weaver (Ref. 14) evaluate various curb designs and configurations and their effects on vehicle behavior. The results are reported so that criteria may be developed on the use of curb types based on selected design intents.

AASHTO's *A Policy on Geometric Design of Highways & Streets*, 1990 (Ref. 2) is a comprehensive policy covering recommended geometric design practices. It includes design controls and criteria, elements of design, cross section elements, and rural and urban arterials. This reference provides many of the standards observed in much of the literature referenced in this report.

## **CAPACITY ANALYSES AND WEAVING AREAS**

The following works include some of the manuals referred to in the capacity analyses performed in this report. Also included are works that critique these analysis methods and works that employ these methods in topics related to this study.

Pignataro and McShane (Ref. 17) evaluate the procedures outlined in the *1965 Highway Capacity Manual* for weaving area analysis and design, and a new procedure is developed. It was generally determined that the *1965 Highway Capacity Manual's* methods were not very accurate. The new procedures were developed based on an interactive evaluation of macroscopic (calibration of microscopic data using a range of facilities and conditions) and microscopic data (lane changing, concentrations within sections, extent of segregation, and some analytical modeling). The procedure, along with a detail of a FORTRAN program to be used as a computational aid, are included in this study.

In *Improving Traffic Flow at Transfer Roadways on Collector-Distributor Type Expressways*, (Ref. 10) McDermott and McLean perform a study along a 6.5 mile section of a Chicago expressway utilizing collector-distributor roadways to minimize weaving and to expedite traffic flow. Studies and experiments were performed to evaluate the effectiveness of various methods of signing, pavement markings, and other methods of channelization and traffic control. Recommendations are made for possible improvements to be implemented along that particular section of roadway.

Hansell (Ref. 6) compares operation and accidents at four interchanges equipped with collector-distributor roads and three without. The results show collector-distributor roads to be an effective method of minimizing weaving, improving operation, and generally improving design. Weaving type accidents were significantly lower for interchanges equipped with collector-distributor roads and operating costs were lower, but construction costs and maintenance costs were higher.

Pignataro, McShane, Crowley, Lee, and Casey (Ref. 18) define saturation and the causes of saturation, and then evaluate the effectiveness of various treatments. Extensive coverage is given for right-turn lanes, right-turn-on-red operations, turn bay signal treatments, and delay with and without turn bays.

Pignataro's *Traffic Engineering Theory and Practice* (Ref. 16) is a basic traffic engineering textbook/handbook. Topics relevant to arterial collector-distributor lanes include methods for capacity analysis for urban streets and arterials, weaving sections, access control and accident rates, channelizing lanes, and the need for uniformity in design.

## **SAFETY**

The main focus of this group of studies is safety in design and operating characteristics of arterial streets. Much of the literature found in other sections of this literature review also address safety as this is a most important concern for transportation engineers and policy makers.

In Harwood's report, *Multilane Design Alternatives for Improving Suburban Highways* (Ref. 7), safety, operational, and cost characteristics of selected multilane design alternatives for suburban highways are compared and evaluated. Accident data for various street designs are presented. Several highway design alternatives are also presented along with their respective advantages and disadvantages. Based on several critical factors and existing conditions, a process for determining an appropriate design alternative for use on a suburban highway is suggested.

Datta, Parker, and Randolph (Ref. 3) examine urban arterial traffic accidents to identify causal elements and countermeasures to reduce their rate and severity. Roadway segments located in 19 metropolitan areas were analyzed. The result of this study includes a set of guidelines to be used to identify accident problems and select countermeasures.

## **GENERAL**

The works discussed below are comprehensive works that include many facets of arterial design, implementation, and effective, safe operation.

Ward's study (Ref. 24) proposes an improved arterial street system, called the Strategic Arterial Street System (SASS) for Harris County, Texas. The proposed geometric design and operational scheme includes, among other improvements, partial control of access, no left turns, median-divided roadways, and 40 to 50 mph design speeds.

Included in Reference 25 are nine research reports addressing the issue of operational effects of geometrics. The pertinent reports are "Warrants and Guidelines for Continuous Exclusive Right-Turn Lanes" and "Optimum Selection of Access Locations Along Major Arterials."

Kruger's doctoral dissertation (Ref. 8) provides a thorough examination of the issues involved in the design and implementation of a strategic arterial in an urban area. The study involves a discussion of the current needs and trends in urban mobility, a discussion of street classification, and a derivation of planning and design criteria for strategic arterials. Geometric features, intersection control, grade separations, control of access, and pedestrian activity are considered in the development of recommended guidelines for implementation of a strategic arterial. Several models and computer simulation packages are reviewed in the context of strategic arterial analysis. Finally, this dissertation makes recommendations for future direction and research needs in this subject area.

## **SUMMARY**

The literature reviewed above provided the author with a basic understanding and awareness of the issues pertinent to the topic of collector-distributor lanes on arterial streets. These works along with others, cited as references, provided sources of information from which ideas, techniques, and data were extracted. This extracted information was then ordered in a logical and cohesive fashion and provided a basic foundation on which this report was written.



## CHAPTER 3. CONTROL OF ACCESS

### INTRODUCTION

An urban arterial street is a roadway designed to carry large volumes of traffic through urban areas. AASHTO (Ref. 2) categorizes arterials by their level of access control, from a two-lane street with no control of access to a freeway with complete access control. The level of access control incorporated into the design of an arterial street is based on the purpose the facility is to serve. There is an inherent conflict between mobility and access on an urban arterial. On the one hand, the road must provide the capacity to move large volumes of traffic safely and efficiently. On the other hand, abutting properties along the arterial are not to be denied their right of access. The problem arises when development along the arterial, with unlimited access privileges, begins to have adverse effects on the safety and efficient operations of the facility. The conflict between access and mobility is graphically depicted in Figure 3.1. As can be seen, the greater the degree of mobility, the higher the functional classification of the street. Mobility is considered of primary importance on arterial streets, with service to abutting land only a secondary role of the arterial. The objective of this chapter is to examine techniques by which safety and operating characteristics can be improved on arterials by increasing control over vehicular access to the facility. This study will consider the case of an existing arterial street whose operational characteristics have been diminished by development along the arterial which is inconsistent with the primary function of the facility. Of course, when the design of a new facility is considered, the problems discussed in this report should be recognized and, if possible, avoided.

Many technical solutions to the conflict between mobility and access, which can be easily and cost effectively implemented, are available. Unfortunately, the solution to the problems of access control is not a simple one, as many legal and political issues must be considered as well. This chapter will focus on various access control problems and possible solutions from an engineering standpoint. Legal or political issues which should be taken into consideration will be mentioned; however, the many legal implications of access control are beyond the scope of this report. For a comprehensive treatment of this subject matter the reader is referred to Netherton (Ref. 12).

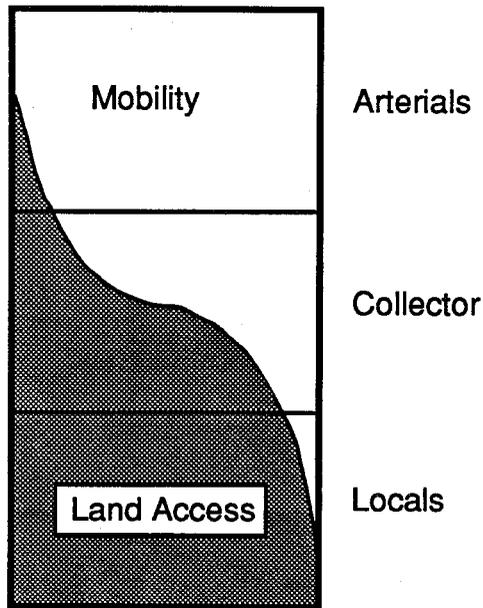


Figure 3.1 Relationship between mobility and land access for various street classifications (Ref.2).

### OBJECTIVES OF ACCESS CONTROL

In order to develop the most effective methods for the control of access, the objectives of such an undertaking and possible methods of implementing those objectives must be clearly identified. Only then can the alternatives be evaluated in order to arrive at an optimal solution.

A primary objective in the implementation of some form of access control is to improve safety, both to vehicles travelling along the arterial and to those vehicles entering into or departing from the traffic stream. Several studies implicate driveway turning movements as a major cause of accidents along arterial streets. Statistics from the 1970 National Safety Council as reported by Glennon (Ref. 4) indicate that 4.9 percent of all urban accidents and 6.0 percent of all rural accidents involve vehicles performing driveway maneuvers. A graph depicting numbers of accidents versus average daily traffic, depending upon level of access control is shown in Figure 3.2. It can be easily seen from this graph that the curve representing facilities with low level of access (defined as less than four access points per mile) shows, in general, fewer accidents per million entering vehicles than that for facilities with a moderate level of access (defined as between

12 and 16 access points per mile). Facilities with a high level of access (24 to 28 access points per mile) have, by far, the highest accident rates. Other studies report slightly different results; however, it is certainly evident that driveway maneuvers are responsible for a significant percentage of accidents, and limiting driveway operations by controlling access, can reduce these accident rates .

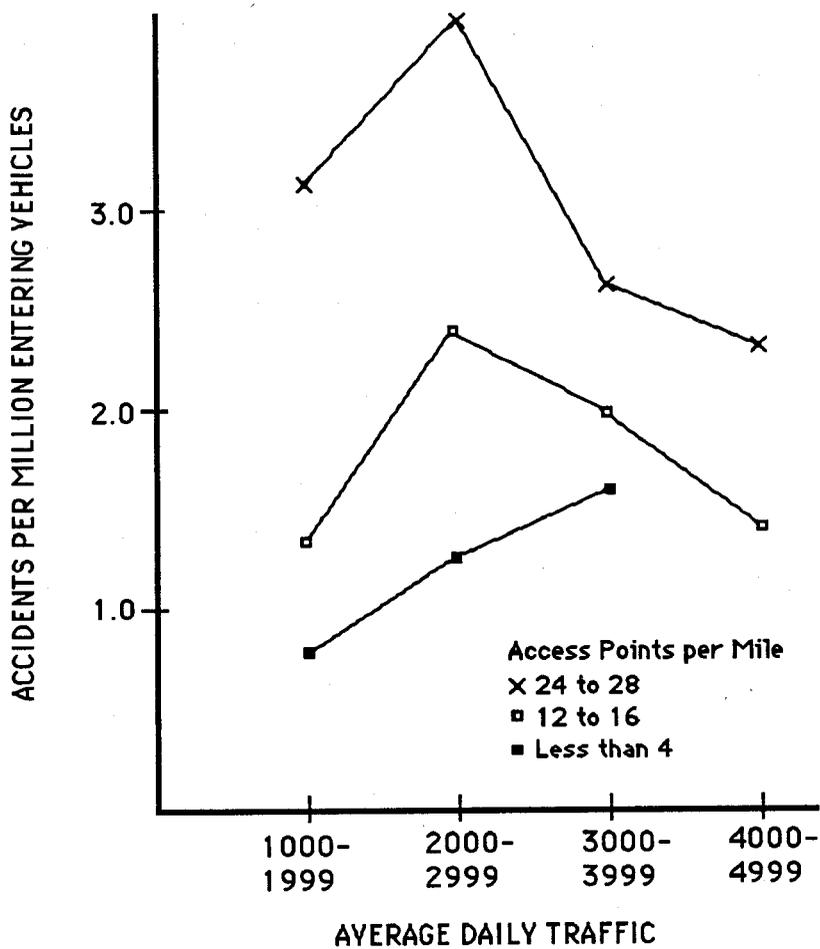


Figure 3.2. Driveway accident frequency based on level of access. (Adapted from Ref. 13).

The other major factor which may warrant the implementation of some form of access control is the impact of the maneuvers of entering or exiting vehicles on facility operations, namely reductions in capacity, vehicle operating speeds, and an increase in motorist delay. This can be caused by several movements including the following:

- 1) Vehicles decelerating to prepare to turn, causing following vehicles to slow down or stop and creating friction with vehicles in the adjacent lanes,
- 2) vehicles entering the traffic stream by a turning maneuver without an appropriately large gap between it and the next approaching vehicle, causing that vehicle and those following to slow down or stop, and
- 3) vehicle overhangs encroaching on adjacent lanes during turning movements, thus imparting friction to vehicles travelling in adjacent lanes.

Other vehicle movements which have negative effects on traffic operations such as left turns across opposing traffic streams can be controlled by such traffic control devices as medians. While medians are a form of access control, they will not be discussed in this report, as they do not fall into the realm of collector-distributor lanes.

The two major goals that may be used to justify the implementation of some form of access control, therefore, are increased safety and improved operations. The following objectives can now be established.

- 1) Limit access to the land adjacent to the arterial to the minimum that is feasible and practicable.
- 2) In places where access is permitted, restrict possible vehicle movements so as to have the least negative impact on traffic operations, primarily on the arterial, and secondly, on the facility for which access is being permitted.
- 3) Design facilities where access is permitted so as to minimize the number of vehicle conflict points, thus reducing the potential for accidents. Where points of conflict are inevitable, the geometrics should minimize the severity of accidents that might occur.

## **METHODS OF ACCESS CONTROL**

The objectives presented above can be approached from several directions. Access can be limited by zoning the adjacent land to control its development, by imposing legal restrictions on the amount of access a property may be allowed, by applying design standards which include features that physically limit access, and by improving the geometry of the access points. The first two approaches involve policy decisions and will be addressed briefly in this chapter. Control of

access through engineered design will be dealt with in some detail also in this chapter. Methods for geometrically improving points of access will be discussed in Chapter 4. In addition, not all arterial streets provide suitable existing conditions to warrant the implementation of a collector-distributor lane. In Chapter 5 various potential existing conditions will be considered along an arterial to determine whether a collector-distributor lane is justified or necessary. The remainder of the discussion in this chapter is based on the assumption that a collector-distributor lane is warranted.

### **Legal Methods**

Several methods exist to control vehicular access to land adjacent to an arterial street. The most desirable method is to design the facility and resolve legal and political issues before construction so that future development does not conflict with the mobility function of the arterial. Unfortunately, in many situations, roadside development does have an adverse effect on arterial operations. This may be a result of the construction of the facility following the development of the land so that right-of-way was limited and development was already inconsistent with the arterial's mobility function. Other times, financial, legal, or political considerations may have resulted in a less than optimal solution. A common scenario is one in which the facility had been constructed and then surrounding development exploded resulting in few options for the later implementation of access control and a facility with insufficient capacity to adequately meet the volume demands placed on it.

One set of alternatives includes the various legal methods of access control. The most common of these is acquiring right-of-way and controlling land access by the power of eminent domain, and controlling land development and land use by zoning laws and licensing. These methods force adjacent land development to conform with standards which are consistent with the arterial street's function of mobility. Other methods in this category include the purchase of the right-of-way, compensating the owners of properties that have been denied access, contractual agreements, and nuisance law (Ref. 12). Ideally, policy solutions should complement engineering solutions. Engineers and policy makers must work together to make these methods work effectively.

The remainder of this chapter deals with methods of access control through engineered design.

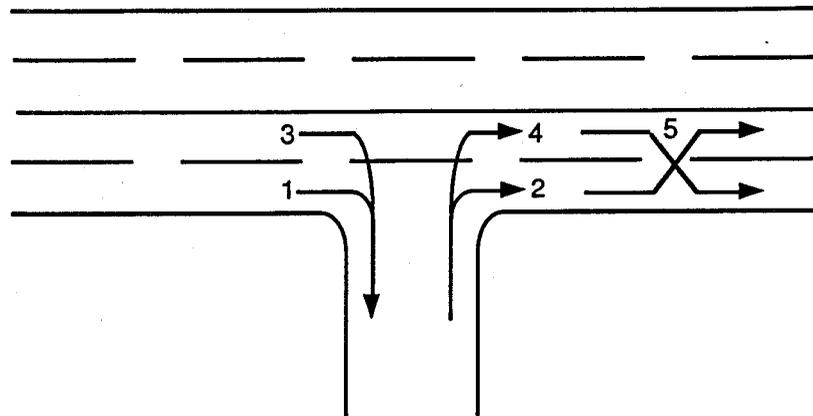
## **Control of Access Through Engineered Design**

Partial or total control of access can be implemented by various design techniques. A collector-distributor road on a freeway serves the function of controlling access to the freeway by collecting traffic from abutting land and other facilities and then providing this traffic with access only at certain points along the freeway, thus minimizing the number of potential points of conflict. In addition, at the points where traffic is permitted to enter and exit the freeway, the geometric design of the access points (usually on-ramps and off-ramps) is such that vehicles can accelerate or decelerate so as to reduce friction and minimize interference with the through traffic lanes. Similar design principles can be considered for use on arterial streets. Allowances must be made for limited right-of-way conditions on existing arterials as well as for the greater importance arterial streets have in the role of land access (again, the reader is referred to Figure 3.1).

Because of the low level of access control along many arterial streets, there exist basic differences in the number and types of conflict points that may be encountered along the arterial as compared with a freeway. An important assumption made for the design considerations in this report is the existence of a continuous median barrier along the arterial between major intersections. Figure 3.3 depicts the basic conflict points which a driver may encounter along an arterial, based on this assumption. The assumption of a continuous median is important because it eliminates opposing left turns from crossing through traffic streams to enter driveways or small streets, and it prevents left turns from driveways or minor streets, again, through traffic streams. It is essential to eliminate these maneuvers if a collector-distributor lane is to be implemented. The addition of a continuous median can provide significant improvements to the safety and operation of an arterial street; however, the design of, effects of, and legal and political issues associated with various median designs and their implementation is beyond the scope of this report.

Referring to Figure 3.3, there are five important points of conflict which need to be considered. These conflict points must either be eliminated or reduced in number, or their negative effects on arterial operations reduced in order to improve arterial operations and increase driver safety.

The first issue to be considered is how to prevent vehicles from gaining unlimited access anywhere along the arterial. In Chapter 4, techniques for limiting driveway access points along the arterial are discussed. However, a driveway is a facility which is designed to allow vehicular access along a street where access would otherwise be physically impossible. To have effective control over access, the places where it is physically possible for a vehicle to gain access to the arterial street between intersections must be limited to specific points (i.e. driveways) which can then be subject to appropriate design standards as discussed in Chapter 4. This access control can be



1. Right turn from arterial
  - following vehicles forced to decelerate or stop
  - turning vehicle encroaches on adjacent lane
  
2. Right turn from other facility
  - driver turns with insufficient gap in through traffic causing through traffic to decelerate or stop
  - turning vehicle encroaches on adjacent arterial lane
  - vehicles in lanes to right forced to decelerate or stop
  
3. Illegal right turn from wrong lane
  - following vehicles forced to decelerate or stop
  - vehicles in lanes to right forced to decelerate or stop
  
4. Illegal right turn from other facility onto wrong arterial lane
  - may force all through traffic to decelerate or stop
  - following vehicles on other facility forced to decelerate or stop
  
5. Weaving
  - vehicles in both lanes forced to decelerate or stop

Figure 3.3 Basic conflict types between major intersections on median-divided arterial streets.

provided in several ways including construction of a physical barrier such as a curb, fence, or railing. The barrier should be continuous everywhere except where an opening is allowed for a driveway or a minor street. Since space is usually too restrictive to provide a shoulder area, the barrier should be designed so as to not be considered an obstruction by motorists which could negatively affect traffic operations. In many cases, this physical barrier is provided by curbs and sidewalks.

The next issue to be considered is how to separate the lane designated as the collector-distributor from the through traffic. By physically separating the through lanes of traffic from the effects of vehicles entering and exiting the arterial, the effects of conflict points described in Figure 3.3, with the exception of weaving, can be constrained to only the right-most lane. The problem of weaving will be addressed later. On freeways, where sufficient right-of-way is provided, this is done by physically separating the collector-distributor from the through lanes as a separate road. Access to the through lanes can then be totally controlled.

Space limitations along existing urban arterials make total physical separation of the right-most lane impossible in most situations. One possible method that may be considered for separating the collector-distributor lane from the through lanes is a narrow raised island, space permitting. Openings in the island can provide access between the through lanes and the collector-distributor lane at limited strategic points. However, to avoid over complicating traffic control, this is not recommend. Actual field testing of this technique was not possible for this report, however, certain disadvantages to this method can be identified without actual field experimentation. First, this method of channelization is not standard practice. This may lead to uncertainty in driver behavior which is always undesirable. Second, there will undoubtedly be a lot of driver frustration when turnoffs are passed which the driver cannot access. This will also lead to complaints from businesses in front of which these barriers are constructed, particularly those businesses which rely heavily on passerby business. Next, due to space limitations, the island may be extremely narrow, perhaps only a curb-type barrier, causing it to be difficult to see and possibly dangerous, particularly in light of the fact that this method is not standard practice and drivers may not be expecting any sort of channelizing device. Finally, while turning maneuvers into and out of minor facilities may be separated from the through lanes, the traffic entering the through lanes will do so only at the allowed points of access. However, unlike the way in which freeway access is limited to only certain points, the arterial collector-distributor lane will have no transition facility such as an on-ramp or off-ramp to allow vehicles to accelerate or decelerate while preparing to merge. In addition, on-ramps and off-ramps are separate facilities along freeways, whereas, by providing only an opening in the island, vehicles perform both operations at the same

point. Clearly there will be a resulting weaving problem as slow moving vehicles attempt to enter through traffic at the same point where faster moving vehicles are attempting to leave the through lanes. For these significant reasons a physical separation is not recommended.

Another method of separating the movements of the collector-distributor lane from the through lanes is by a combination of sufficient lane width and appropriate pavement markings. It is crucial that the width of the collector-distributor lane be sufficient to prevent any encroachment into the through lanes by vehicle maneuvers into and out of that lane. This lane width, along with other geometric considerations, including intersection and driveway curb return radius and driveway throat width, are based on the design vehicle's dimensions and swept path. Driveway and intersection design considerations will be discussed in Chapter 4.

The design vehicle chosen to determine arterial geometrics should represent the largest vehicle, particularly that with the largest turn radius and swept path, that will regularly use the facility. If the percentage of large trucks using the arterial is significant the design vehicle WB-50 (large semitrailer) should be chosen. For many major arterials the design vehicle WB-40 (intermediate semitrailer) may be sufficient. Selected dimensions, according to AASHTO specifications (Ref. 2), for the WB-40 and WB-50 are compared with those of a passenger car in Table 3.1.

TABLE 3.1 CRITICAL DIMENSIONS OF SELECTED DESIGN VEHICLES  
(Adapted from Ref. 2)

<u>Design Vehicle</u>	<u>Overall</u>		<u>Overhang</u>		<u>Min Turn Radius</u>	<u>Min Inside Radius</u>
	<u>Width</u>	<u>Length</u>	<u>Front</u>	<u>Rear</u>		
Passenger car	7	19	3	5	24	15.3
WB-40	8.5	50	4	6	40	19.9
WB-50	8.5	55	3	2	45	19.8

The design vehicle recommended by Azzeh (Ref. 1) has approximately the same dimensions as the AASHTO design vehicle, and a slightly larger minimum turning radius (twenty eight feet). Azzeh uses this design vehicle to evaluate techniques for controlling access. It can be seen that the minimum turning radii of even the passenger car would require a prohibitively wide lane if the vehicles were to have to make a ninety-degree turn without sufficient driveway geometrics and curb-return radii to help alleviate the problem. By the use of proper driveway and intersection geometrics, discussed in the next chapter, the collector-distributor lane width can be kept reasonable. All the literature reviewed arrive at the same design recommendations for lane width. Ward (Ref. 24) recommends twelve foot lanes as being desirable for a right-side auxiliary lane on strategic arterials. Kruger (Ref. 8) suggests an eleven foot minimum width, with twelve feet again being desirable. AASHTO (Ref. 2) and Neuman (Ref. 13) both recommend twelve foot lanes. It is also good practice to keep the maximum lane width below fourteen feet, as drivers begin to treat widths greater than this as two lanes. If the space is available, a clearly marked shoulder area may be provided.

To indicate to motorists that the right-most lane has different operating characteristics than the adjacent through lanes, without a physical barrier separation, some unique pavement markings and signing must be employed. The Manual on Uniform Traffic Control Devices (MUTCD) (Ref. 23) lists some general principles for longitudinal pavement markings. It advises that white lines can be used to delineate separation of traffic flows in the same direction. Also, broken lines are permissive in character while solid lines are more restrictive in character. Finally, width of line indicates degree of emphasis, a normal line width being between four and six inches, while wide lines being at least twice the width of normal lines. The MUTCD provides the following recommended usage for a solid white line:

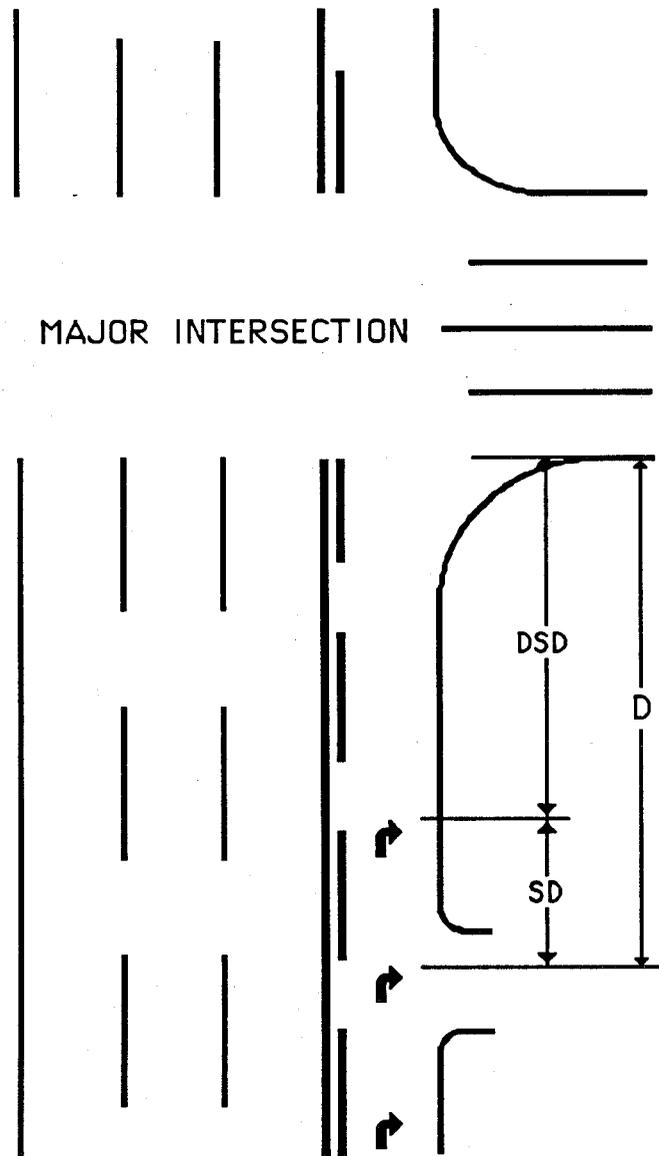
A normal, solid white line is used to delineate the edge of a path where travel in the same direction is permitted on both sides of the line, but crossing the line is discouraged.... A solid white line is used for emphasis where crossing requires unusual care. It is frequently used as a line to delineate left or right-turn lanes. (Ref. 23, p.3A-3)

These recommended uses match the results desired for delineating a collector-distributor lane. However, the white line is used so frequently that the motorist may attach no special significance to it's use in indicating a collector-distributor lane. The goal of the markings should be to indicate to motorists that the right-most lane is for special maneuvers, and not a through lane.

At the same time it must not be confusing or totally unrecognizable to drivers. Kruger (Ref. 8) recommends several possible signing and marking alternatives for a similar type lane. Figure 3.4 represents markings which would be most suitable for designating a collector-distributor lane. It is based on one of Kruger's recommendations, with the following modifications. First, what primarily separates the collector-distributor lane concept from that of a continuous right-turn lane is that the collector-distributor lane does not become a right-turn-only lane at any intersection, either a minor intersection or an intersection with another major facility. There are several reasons for this. First, major arterials frequently facilitate mass transit operations. Lanes allowing only right-turns at intersections would force local buses that must continue straight, to merge into the through traffic lanes before every intersection and then return to the collector-distributor lane after clearing each intersection. Since the goal of the collector-distributor lane is to separate slower moving vehicles, and those that frequently stop, from the the collector-distributor that do not wish to turn right, and vehicles on the through lanes that do through traffic lanes, this is very undesirable. Also, by creating a right-turn-only lane at intersections, a weaving area will be created close to the intersections, between vehicles using wish to turn right. If a right-turn lane is not warranted by high turning volumes, vehicles could either turn right or continue through the intersection in the collector-distributor lane.

The collector-distributor lane should be continued past the intersection. In cases where a right-turn lane is warranted by high turning volumes, an additional right-turn-only lane may be added to the right of the collector-distributor lane as depicted in Figure 3.5. This is preferable to making the collector-distributor lane become a right-turn-only lane because any weaving situation as described above will take place in the collector-distributor lane and not in the through lanes. Only in situations where a right lane is necessary, but limitations in right-of-way prohibits construction of an additional lane, should the collector-distributor lane become a right-turn-only lane.

The recommended markings for designating the collector-distributor lane are a parallel solid white line and dashed white line, the dashed white line being closer to the curb. The solid white line along the through lanes will indicate higher speeds, with through-lane characteristics, and that the right-most lane is for limited use only. The dashed white line along the collector-distributor lane will encourage motorists that have just turned onto the arterial to leave the collector-distributor lane, but the solid white line indicates to these motorists that caution must be used in merging into these through lanes. Pavement markings consisting of right-turn arrows are recommended between major intersections so as to encourage through traffic to exit this lane. These markings should stop as the arterial approaches a major intersection, at a reasonable



MAJOR INTERSECTION

D = recommended distance from intersection  
at which pavement markings end  
DSD = decision sight distance  
SP = regular right turn arrow spacing

Figure 3.4 Markings for collector-distributor lane without required right-turn-only lane.

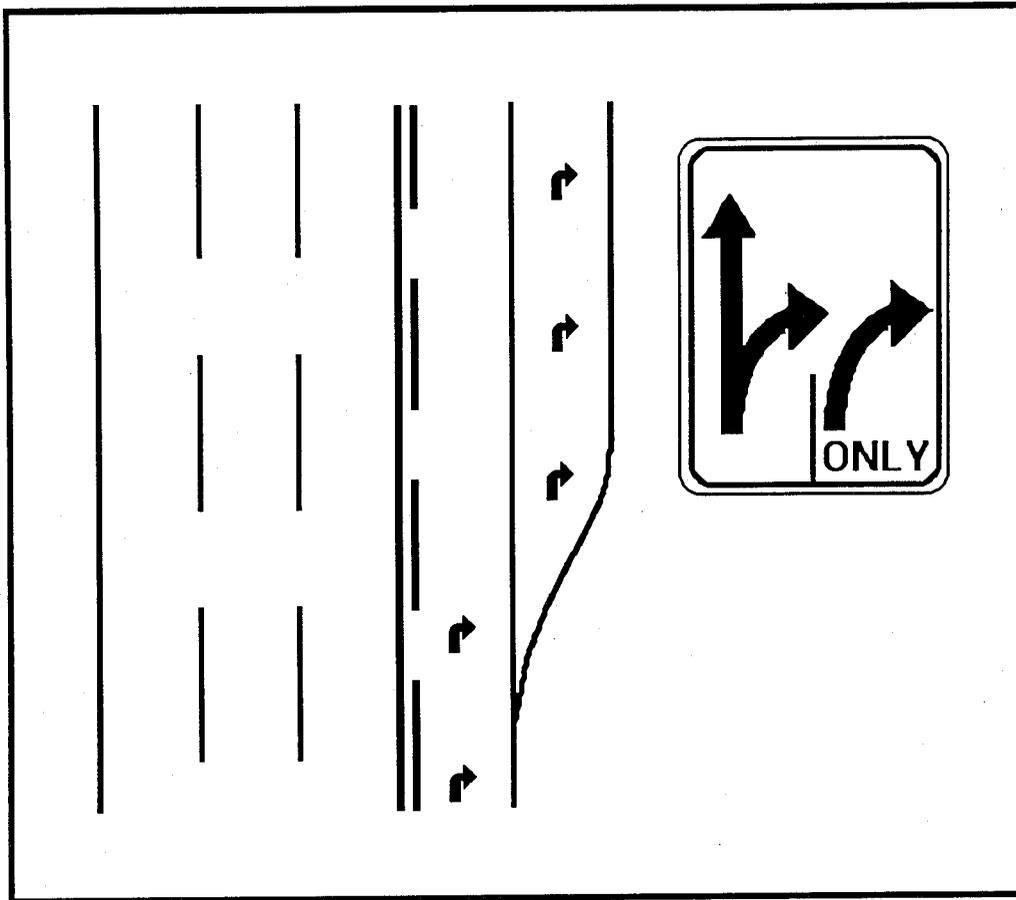


Figure 3.5 Collector-distributor lane delineation and signing when right-turn-only lane is required.

distance from the intersection so as to prevent vehicles from merging to the left to avoid being forced to turn right. A logical recommendation for this distance is that the last right-arrow pavement marking disappears from the driver's line of sight (under the vehicle) and it is apparent to the driver that the markings have stopped at the point of decision sight distance to the intersection. Neuman (Ref. 13) defines decision sight distance, basically, as that distance in which the driver perceives some unexpected information (i.e. the fact that they are approaching an intersection) and then decides upon and executes a selected maneuver. This distance can be represented by the following formula:

$$D = DSD + SP \quad \text{where}$$

D is the recommended distance from the intersection at which pavement markings end,

DSD is the decision sight distance, and

SP is the regular spacing between the right-turn arrows.

This formula positions the last arrow so that the driver will see the approaching intersection after the last right-turn arrow has passed out of sight and it is clear to the driver that no more arrows will follow. These dimensions are also depicted in Figure 3.4. This simple formula is a minimum distance, but should be sufficient in typical situations since, statistically, most drivers are repeat drivers and will know that an intersection is approaching and perform required lane changes as they approach the intersection, regardless of the pavement markings.

## **SUMMARY**

The purpose of this chapter was to define the goals and objectives of implementing some form of access control on an urban arterial street. Once these objectives were established, several methods for limiting access to the arterial were discussed and recommendations were made. Finally, methods of designating the right-most lane of the arterial as the collector-distributor lane were discussed. One of the methods of limiting access that was discussed in this chapter was to minimize numbers of minor streets and driveways. In the next chapter, design alternatives to improve the safety and operations at the minor streets and driveways that can be accessed by the arterial street are discussed.

## **CHAPTER 4. DRIVEWAY AND INTERSECTION DESIGN CONSIDERATIONS**

### **INTRODUCTION**

Chapter 3 discussed the importance of controlling access and separating the collector-distributor lane from the through-traffic lanes. Even with effective access control measures implemented, points still exist along the arterial where access must be provided, either to abutting land by way of a driveway or to a small collector street between major cross streets, or to the major cross streets themselves. Controlling access to and from the arterial can have potential benefits to safe and efficient arterial operations, and even operations on connecting facilities. These benefits can potentially be negated by improper design of the points of access. This chapter will address basic design practices that can be used to improve the operations that occur as a vehicle enters or leaves the arterial. These design recommendations complement the recommendations in Chapter 3.

The recommendations of Chapter 3 may, depending on right-of-way restrictions or local policies, be easier to implement than those presented in this chapter as those that follow may require alterations to private property. Again, the legal issues involved in implementing improvements on private property are beyond consideration in this report. In many cases, local design standards, which are generally controlled by policy makers, may allow for inadequate or inappropriate design. Having these standards brought up to a suitable level is one possible course of action. The engineer proposing the higher standards may point out the advantages that may be realized by property owners along the arterial who are affected by these standards, such as improved operations on the arterial, and most importantly, improved safety at the points of access. These improvements translate to the affected business as an increased number of potential customers, reduced delay and aggravation to those customers, and lower risk of accidents adjacent to the place of business.

### **ELIMINATING POINTS OF ACCESS**

One of the objectives of implementing access control, outlined in Chapter 3, was to limit access to and from the land adjacent to the arterial to the feasible and practicable minimum. Two obvious ways to do this are to reduce the number of minor intersections and to reduce the number of driveways.

Reducing the number of minor intersections is often overlooked as a possible method of access control. Often, because a street already exists, it is viewed as permanent. However, it may be feasible to block the end of the street, either by some form of constructed raised curb or by a barrier or fence. Certainly, the decision to implement such a form of access control must be considered carefully. The major consideration, of course, is whether the street network will provide access to the arterial at some other point so as to not trap vehicles. Also, the surrounding street system must be able to handle the increased through traffic that has been rerouted from the closed street without being overburdened. There are several advantages to blocking a minor street in this way. Of primary importance is the elimination of conflict points described in Figure 3.3 (Chapter 3) and the associated benefits of doing so. Other benefits which may be derived from blocking a minor street include the benefit of safety and peace and quiet to the residents who now reside on a dead end street as opposed to a through street. Also, a series of blocked streets may result in a safer, more exclusive neighborhood as access to the neighborhood will be limited and through traffic will be reduced. The disadvantages of blocking a minor street include the reduction in mobility and land access that was once provided by that street, and possible objections by residents who, as a result of the blockage, will have more traffic routed onto their streets. In the long run, the increased mobility on the arterial street will be of greater benefit to overall transportation system effectiveness than will be the cost of lost mobility on a few minor streets. In addition, the cost of greater traffic on a few select streets in a neighborhood may be offset by the overall reduction in the number of streets carrying through traffic.

The second method of limiting access to the arterial is to limit the number of driveways. The minimum spacing of driveways on an arterial with a large number of access points must be regulated by policy decisions. There are several factors that must be considered when recommending a minimum spacing for driveways. The speed of travel on the arterial will determine the rate at which conflict points will be reached by a vehicle. The comfortable rate of acceleration for the design vehicle will determine the amount of space vehicles will need before being able to merge into through-traffic lanes, and the comfortable rate of deceleration will determine the length of pavement needed for the vehicle to slow to a reasonable turning speed. It is desirable to have driveways spaced so that the acceleration and deceleration maneuvers from one driveway do not interfere with those of an adjacent driveway. Azzeh (Ref. 1) suggests the design vehicle performance characteristics shown in Table 4.1. When compared to recommended rates in other studies, these rates tend to push the limits of the general consensus as to what is a comfortable acceleration rate. Glennon (Ref 4), however, recommends driveway spacing (see Table 4.2) which is based on slightly lower rates of acceleration to a desired speed. The rates used seem to

be a little more comfortable, but are still brisk and so the spacings based on those rates, as listed in Table 4.2, will be considered as minimum recommended spacings.

TABLE 4.1 SELECTED VEHICLE PERFORMANCE CHARACTERISTICS (REF. 1)

Deceleration Rate : 8.5 ft/sec-sec

Acceleration Rate :

Speed Attained (mph)	10	15	20	25	30	35	40	45	50
Normal Acceleration Rate (ft/sec-sec)	5.3	4.8	4.4	3.7	3.1	2.5	2.5	2.5	2.5

TABLE 4.2. MINIMUM RECOMMENDED DRIVEWAY SPACING (Ref. 4)

MINIMUM SPACING OF ADJACENT DRIVEWAYS

<u>Highway Speed</u> (mph)	<u>Deceleration Rate</u> (ft/sec-sec)	<u>Acceleration Rate</u> (ft/sec-sec)	<u>Minimum Spacing</u> (feet)
20	8.5	3.0	85
25	8.5	2.5	105
30	8.5	2.1	125
35	8.5	1.7	150
40	.5	1.7	185
45	.5	1.7	230
50	.5	1.7	275

In order to recommend a minimum spacing for driveways based on the information in Table 4.2, the speed of travel on the arterial must be determined. The question is whether to choose the speed of travel on the through lanes or the speed in the collector-distributor lane which will be considerably lower. The traffic which will need to perform the acceleration and deceleration maneuvers will be travelling in the collector-distributor lane and so one may choose a low speed of perhaps twenty miles per hour as the appropriate speed on which the driveway spacing is based. Ideally, however, the spacing should be based on the speed of the through-traffic lanes since the goal of a minimum driveway spacing is to raise the operational characteristics of the collector-distributor lane so as to approach the operational characteristics of the through lanes. By choosing a lower speed as a basis for minimum driveway spacing, the operational characteristics of the collector-distributor lane will be, theoretically, constrained by the lower minimum driveway spacing which will, in turn, have a detrimental effect on through-lane operational characteristics. Therefore, the highway speed chosen by which minimum driveway spacing is to be selected should be the speed of the through lanes of traffic. Of course, the resulting recommended driveway spacing is still a minimum for that speed, and in each situation, the maximum spacing that is practicable should be used.

Once a desirable minimum driveway spacing is decided upon, various techniques can be employed to reduce the number of driveways. Legal methods such as zoning represent one type of method for limiting the number of driveways. Some possible legal requirements include limiting the number of driveways based on roadway frontage or based on a maximum number of driveways per land parcel. Another method is to consolidate adjacent driveways possibly by creating a shared access right-of-way between two properties. Properties that have frontage on two streets may be required to have access only to the minor street with no arterial driveway entrance. These methods involve policy decisions which will not be discussed in this report. For a more in-depth review of these methods, the reader is referred to Reference 4.

## **GEOMETRIC DESIGN OF DRIVEWAYS**

The first section of this chapter was based on the first objective of access control outlined in Chapter 3. The remainder of this chapter will concentrate on meeting the second and third access control objectives. The second access control objective states that, in places where access is permitted, possible vehicle movements should be restricted so as to have the least negative impact on traffic operations, primarily on the arterial, and secondly, on the facility from which access is permitted. The third objective states that facilities from which access is permitted should be designed so as to minimize the number of vehicle conflict points, thus reducing the

accident potential. Where points of conflict are inevitable the geometrics should minimize possible accident severity. These objectives can be met through the use of appropriate geometric design techniques which will now be discussed.

Various driveway features can be designed to minimize the impact on the through traffic by vehicles using the driveways. The result of a successful driveway plan is the ability to allow vehicles to exit the traffic stream quickly and safely without conflicts with following vehicles and vehicles in adjacent lanes. In the same way, the driveway will allow vehicles to enter the traffic stream without causing delay to vehicles in the collector-distributor lane or encroaching on adjacent lanes. These goals can be achieved by adequate effective approach width, sufficient throat width, large enough curb-return radii, and smooth vertical transitions. Mounce (Ref. 11) measures the effectiveness of these methods of improvement by fuel consumption, while Neuman (Ref. 13) considers minimizing hazards and delay to motorists. Comparisons of the recommended dimensions in these two studies show the numbers to be very similar, with the numbers recommended by Neuman being, in general, slightly more conservative. The similarities in these numbers are logical, since minimizing delay and reducing fuel consumption are highly-correlated measures of effectiveness. Depicted in Figures 4.1, 4.2, and 4.3 are three possible driveway designs with the dimensions based on Neuman's slightly more conservative numbers. The first of these, depicted in Figure 4.1 is a single, two-way driveway. The advantage of such a driveway is that it keeps the numbers of conflict points with the through-traffic stream to a minimum. Such a driveway may, however, be less effective than the other alternatives because vehicles entering the driveway at high speeds, which is desirable from the through traffic standpoint, may experience head-on conflict with vehicles preparing to exit the driveway. Figure 4.2 depicts a possible solution to this problem. By physically separating the entering and exiting vehicles with a median island, the potential for head-on conflict is reduced. Figure 4.3 represents even greater refinement in the solution of the head-on conflict problem. In addition, the smaller angles for entry to and exit from the driveways allow and encourage vehicles to diverge from the arterial and merge onto the arterial at higher speed. The primary disadvantage of two one-way driveways is that it increases the number of driveways along the arterial. In driveways where arterial frontage is limited, the land area between the two one-way drives can be essentially reproduced in the form of a channelizing island placed in the driveway entrance.

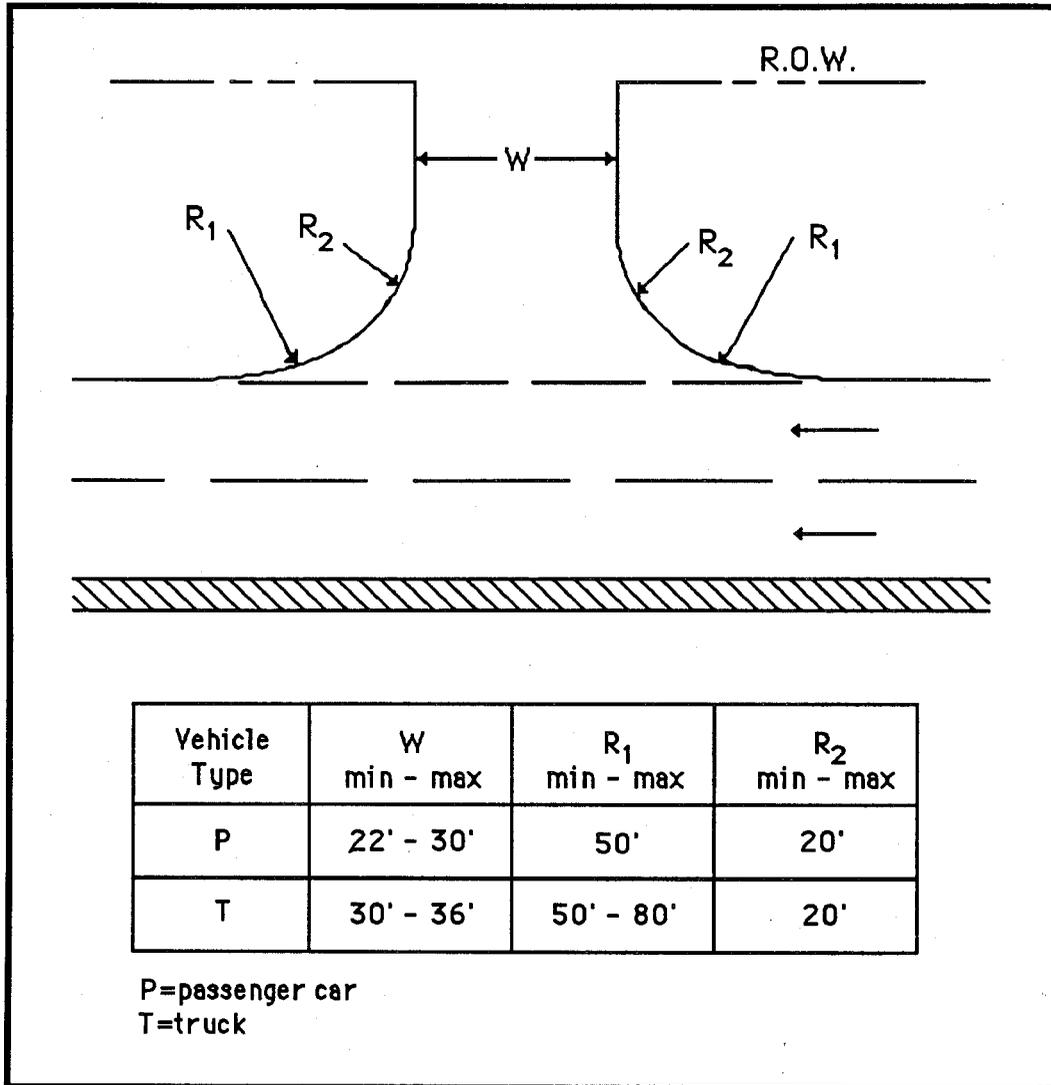


Figure 4.1 Horizontal geometric design for a single driveway entrance. (Ref 13)

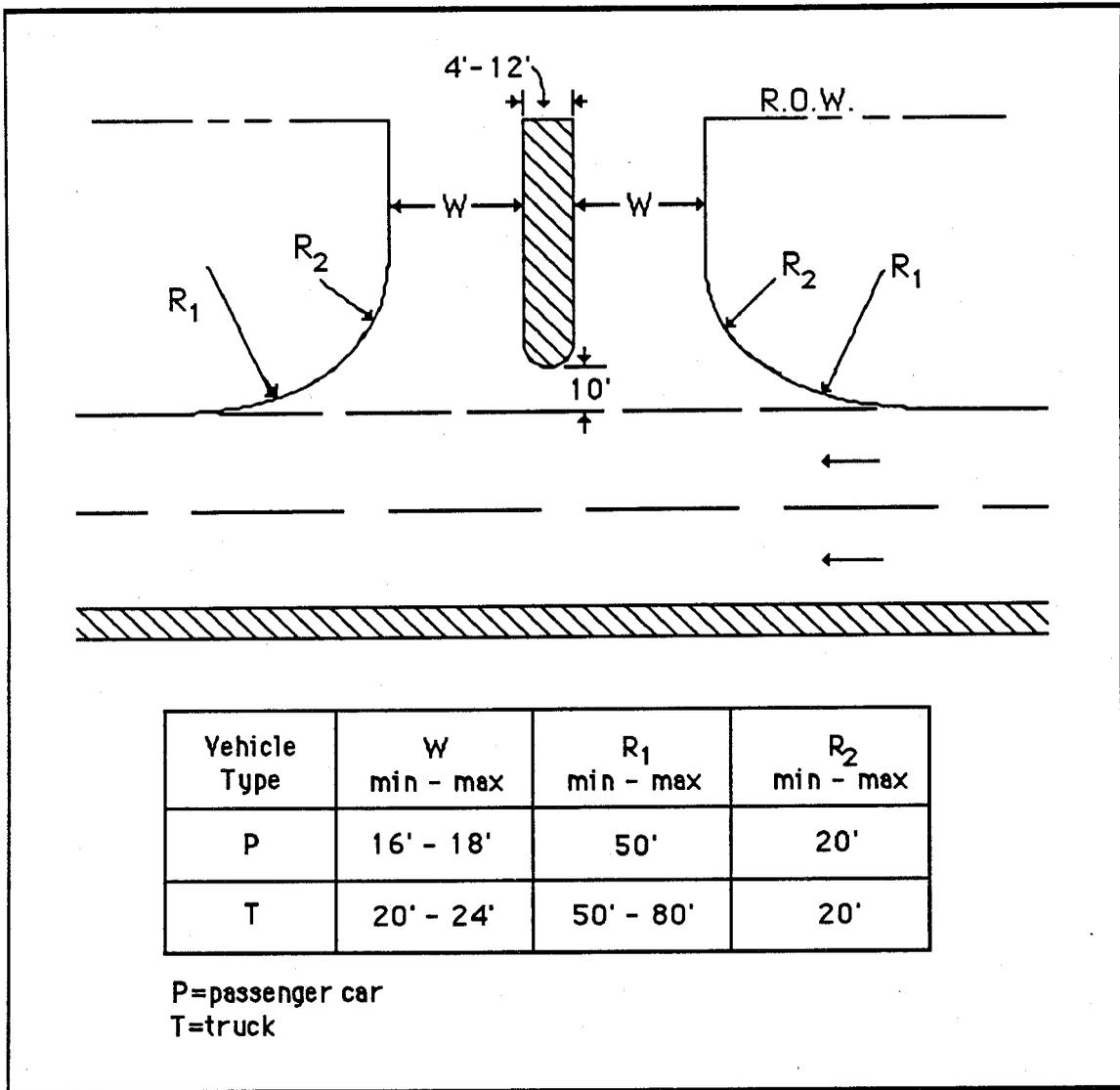


Figure 4.2. Horizontal geometric design for a double driveway entrance. (Ref. 13)

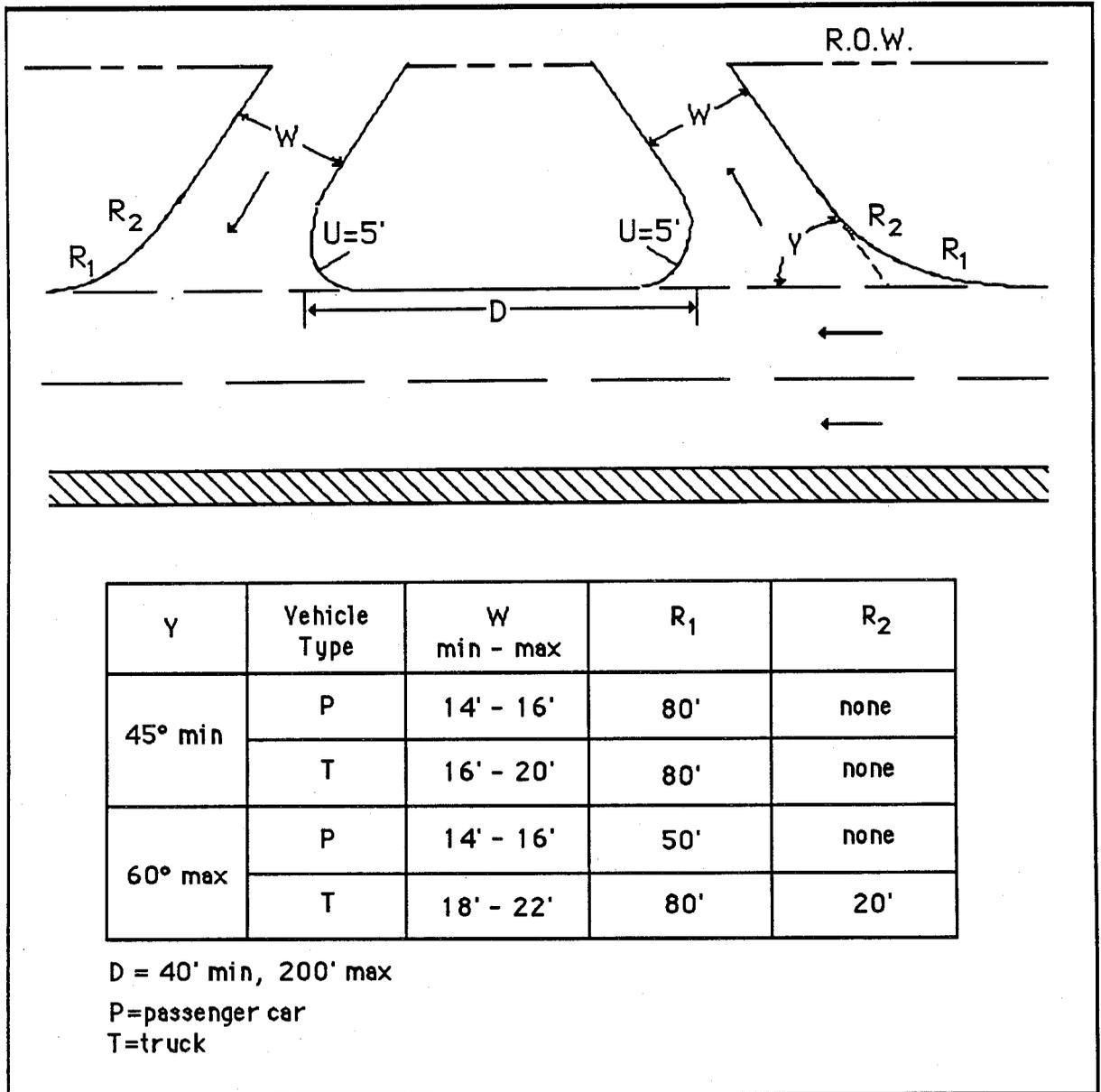


Figure 4.3. Horizontal geometric design for double, one-way driveway. (Ref. 13)

Several other design considerations, when combined with one of the geometric configurations described above, can be used to enhance the driveway operational characteristics. First, it can be required that all driveways be paved. This will provide a smooth, durable surface and will encourage drivers to negotiate the turn into the driveway at a higher speed. Second, on arterials where pedestrians are accommodated with sidewalks, the sidewalk-driveway meeting point can be moved laterally away from the arterial. This will move vehicles waiting for pedestrians to cross the driveway out of the collector-distributor lane, reducing delay to following vehicles. Finally, if the driveway capacity is exceeded by the volume demands put on it, it may be beneficial to add another driveway. While it is undesirable to increase the number of driveways, if the capacity of the driveway is exceeded, traffic may begin queuing in the collector-distributor lane. The benefits of eliminating queuing in the collector-distributor lane greatly outweigh the cost of an added driveway.

The next area of driveway design that is critically important is the vertical alignment. If the change in elevation is too great or if the vertical curvature is too short to provide smooth transition between vertical angles, driveway entry and exit speeds will be greatly reduced due to driver discomfort and vehicles scraping their bottom. Figure 4.4 depicts the typical cross sectional profile of a street and a driveway along with the recommended minimum, desirable, and typical values for the various slopes and vertical curve radii. These figures are based on Mounce's (Ref. 11) findings, with the objective of decreasing fuel consumption.

Geometric design must also be considered at intersections. A thorough analysis of intersection geometric design is not included in this report, however, a few basic features of intersection design to facilitate the operation of the collector-distributor lane will be considered.

## **GEOMETRIC DESIGN CONSIDERATIONS AT INTERSECTIONS**

The next consideration is what happens to the collector-distributor lane at an intersection. A minor intersection can be treated in much the same way as a driveway. At minor intersections, there will usually be no form of traffic control for the arterial; that is, no signal or stop sign. The markings of the collector-distributor lane and the through lanes can continue uninterrupted (see Figure 3.4) as there is no opening in the median. The vertical cross sectional profile will usually be relatively level, so the major geometric feature to be considered is the right-turn curb-return radius. Table 4.3 presents operational characteristics for various corner radii, assuming that approach and departure both occur in the curb lane. It will be noted that the speeds used in this table are not precise. The speed at which a turn can be negotiated is not only

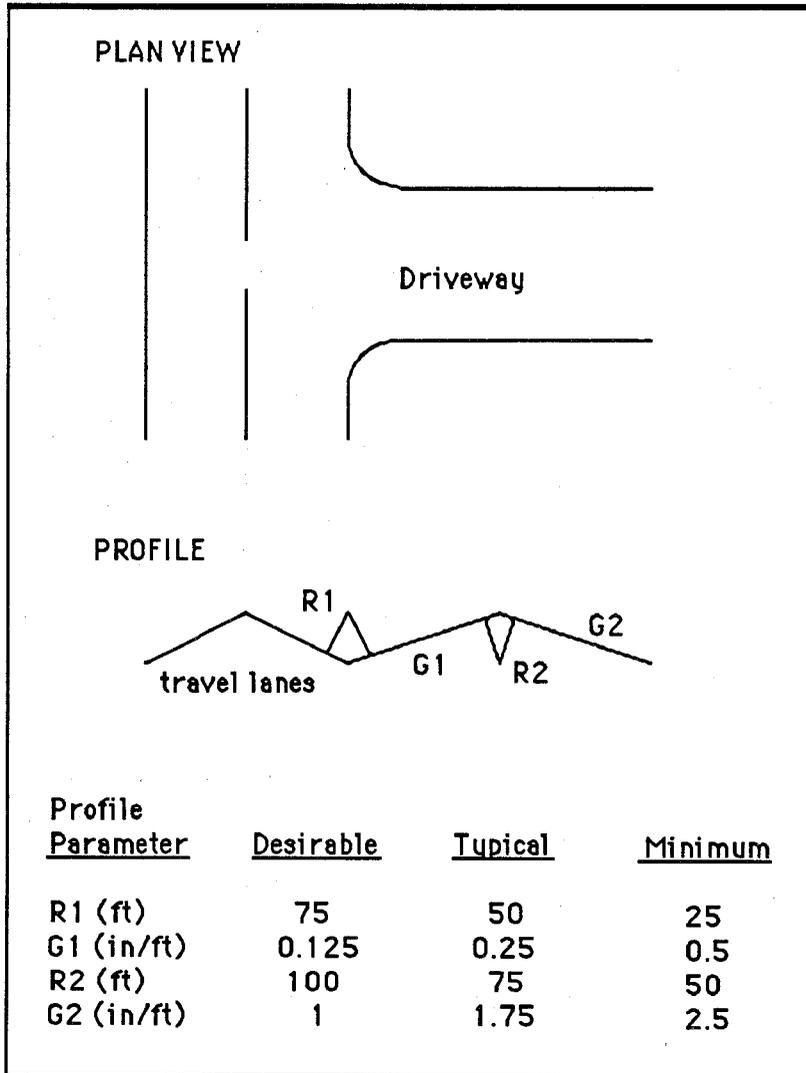


Figure 4.4 Driveway profile characteristics. (Ref. 11)

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<u>Corner Radius (ft)</u>	<u>Operational Characteristics</u>
<5	Not appropriate for even passenger cars
10	Crawl speed turn for passenger cars
20 - 30	Low speed turn for passenger cars, Crawl speed for SU trucks with minor lane encroachment
40	Moderate speed turn for passenger cars, Low speed turn for SU truck, Crawl speed turn for WB-40 or WB-50 with minor lane encroachment
50	Moderate speed turns for all vehicles up to WB-50

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a function of the vehicle's operating characteristics, but also of the level of discomfort a driver is willing to tolerate while turning. The terms that are used describe speed conditions for different corner radii which will not result in great driver discomfort. From this table it can be seen that a corner radius greater than fifty feet is certainly desirable, particularly if the arterial carries a high percentage of large trucks. This corresponds well with the AASHTO (Ref. 2) recommendations which suggest a forty-foot corner radius for corners where large trucks and buses must turn. Even larger radii are recommended if speed reductions will cause problems. The fifty-foot radius is highly recommended as a minimum for major intersections. Minor intersections, which generally carry low volumes of traffic and no large trucks or buses, may only need corner radii of twenty-five or thirty feet. At major intersections, however, the larger radii are recommended.

Finally, it was recommended in Chapter 3 that the collector-distributor lane be continued through major intersections. The reader is referred to Figures 3.4 and 3.5 and the discussion of the advantages and disadvantages involved in continuing the collector-distributor lane as a through lane.

## **SUMMARY**

This chapter presents techniques and design recommendations for driveways and intersections which might contribute to the effectiveness of a collector-distributor lane on an arterial street. The recommendations in the chapter are design guidelines. In many cases, it may be difficult to implement the recommendations due to right-of-way restrictions, funding limitations, or legal or political issues, and it may be necessary to modify design values to adapt the recommendations to specific situations. In the next chapter, the costs and benefits associated with the implementation of a collector-distributor lane on an urban arterial street will be evaluated so as to develop criteria which can be used to determine whether a collector-distributor lane is warranted.

## CHAPTER 5. ANALYSIS OF POTENTIAL IMPROVEMENTS

### INTRODUCTION

Chapters 3 and 4 of this report present techniques which may be employed to implement a collector-distributor lane on an urban arterial street. A discussion of objectives and methods of implementing some form of access control is included. Also discussed are methods of designating a collector-distributor lane and recommended geometric design practices for both the collector-distributor lane and for access facilities such as driveways and minor streets. This chapter presents a quantitative analysis of certain operational characteristics of arterial streets under varying conditions and the resulting potential costs (delays) to motorists based on these conditions. Comparisons are made between operating characteristics on hypothetical typical arterials and on arterials whose characteristics are affected by converting the right-most lane to a collector-distributor lane, and modifying the geometrics and number of access points as described in the previous chapters. For purposes of this analysis, the combination of collector-distributor lane, access control features, and enhanced access point geometrics will be called a collector-distributor system.

In order to evaluate the potential effects that a collector-distributor system may have on an arterial, certain basic, existing conditions must be established. The techniques for evaluating flows and operating speeds on arterials have been adapted from the 1985 *Highway Capacity Manual* (Ref. 22), hereafter referred to as HCM. The HCM uses empirical methods based on observed data from North America, so these analyses may not be applicable in other areas of the world where conditions and drivers may be different. The methodology described below will be employed in the ensuing analyses.

First, typical arterial conditions will be used to create a base condition. The unit along the arterial for which the analyses will be performed is what is referred to in the HCM as a segment. The segment in this study will be a section of arterial between major (signalized) intersections. In arterial capacity analyses, the signalized intersection is considered to be the primary capacity constraint along the arterial. Because the primary purpose of a collector-distributor system is to improve operations between intersections, an assumption will be made in the analyses that the signalized intersections will have no effect on the delay along the arterial. This can be achieved by giving the arterial one hundred percent green time, a green time to cycle length ( $g/C$ ) ratio of one, at all signalized intersections. This assumption, while obviously not a realistic one, will eliminate the effect of traffic signals in causing delay, allowing for consideration of other effects which may

cause delay along the arterial. These other causes of delay, such as the presence of many driveways along the arterial, are precisely what the implementation of a collector-distributor system seeks to reduce or eliminate, and so, the assumption is appropriate for this study.

By definition, in the HCM, basic characteristics along a segment are relatively constant. These characteristics include number of lanes, lane widths, average travel speed, median design, access point density, access point spacing, roadside parking, pedestrian conflicts, and speed limit. To establish a basis for analysis, typical existing arterial conditions will be considered and calculations of delay will be performed. Then, these calculations will be performed for the same arterial conditions with a collector-distributor system. These results will then be compared to determine what, if any, improvements, in terms of delay reduction, were brought about as a result of the collector-distributor system implementation.

The following parameters will be held constant in the before and after implementation analyses. The total number of lanes will remain unchanged, but the widths may be modified as per the design recommendations in Chapter 3. All analyses will be performed for one direction of a median separated, two-way arterial. It will be assumed that no parking was permitted along the right side of the arterial. If parking was permitted, the relative improvements to the operational characteristics of the arterial will be that much greater since parking must be eliminated when the collector-distributor lane is implemented. The posted speed limit will remain unchanged, the assumption being that if a collector-distributor lane is being considered for implementation, conditions are such that the average travel speed is less than the posted speed limit and so the speed limit does not present a constraint to arterial operations. After improvements are made to the arterial, however, it may be possible to exceed the posted speed limit. This report will not consider the legality of doing so, only the ability to do so. The vehicle mix will remain unchanged between before and after situations. Percentage of turning vehicles will be considered to be the same, although the locations where these movements take place and the impact these movements have on through traffic may change. The length of the segments will also be kept constant as will the existing level of surrounding development and population, and no pedestrian interference will be considered in either the before or after scenarios.

The parameters which will be changed so as to create several typical arterial examples are the number of lanes, the volume of traffic on the arterial, and the number of points of access. Within each before and after scenario, the parameters that may change are lane widths and designation, access point density and spacing, and access point design standards. A listing of the parameters which will either change or remain constant, depending on the desired conditions to be replicated, are presented in Table 5.1.

TABLE 5.1 SUMMARY OF VARIATION OF PARAMETERS

---

*Parameters to remain constant in before / after scenarios:*

- number of lanes
- traffic volume
- vehicle mix
- median design
- length of segment
- legal speed limit
- surrounding level of development
- no parking along arterial
- no pedestrian interference
- percentage of vehicles turning
- driveway volumes
- no grades - level terrain

*Parameters that may change in before/after scenarios:*

- lane width
- lane designation
- access point density
- access point design standards

*Parameters that may vary between examples:*

- number of lanes
- access point density
- access point spacing
- traffic volume

---

## **ANALYSES AND RESULTS**

A case study type of analysis of some impacts of collector-distributor system implementation on arterial traffic is presented below. Recommendations of the previous chapters described the collector-distributor system as consisting of three components. These include enhanced horizontal and vertical geometry for access points, reduced numbers of access points (driveways and minor streets), designation of the right-most lane as a collector-distributor lane, and finally, a continuous median barrier limiting left-turn opportunities. Thus, implementation of the complete system would force all mid-block and minor street left turns to become right turns made from the collector-distributor lane. Implementation of the complete system could be done in stages and significant benefits could be obtained from each stage.

The first stage might consist of improving access point geometrics, reducing the number of access points, and designating the right lane as a collector-distributor lane. At this stage, without positive control of left turns, the collector-distributor lane essentially functions as a continuous right-turn lane, since left-turning traffic at mid-block and other locations would continue to use the left traffic lane. Benefits from this stage could come from reduced delay to turning vehicles due to increased right-turning vehicle speeds and reduced interruptions to through traffic streams because through traffic might avoid the designated collector-distributor lane. These potential reductions in delay are separately estimated for a series of hypothetical cases in the following discussion.

### **Establishing Typical Existing Conditions**

The type of facility for which the concept of a collector-distributor system is most applicable is an arterial in an area of moderately high development. Based on the characteristics described in the HCM (Ref. 22, Table 11-2), the design category which is suitable for the analyses that follow is an intermediate principal arterial.

To analyze the effects of implementing a collector-distributor system basic existing conditions, to serve as a foundation for each example, must be established. The first step is to determine the arterial free flow speed. The free flow speed is the average desired speed of all vehicles on the segment. This speed is a best-case scenario which will then be subject to various constraints based on existing limitations along the segment. The HCM suggests a range of free flow speeds for an intermediate principal arterial from thirty to forty miles per hour with a typical value of thirty-three miles per hour. It will be noted that conditions where travel speeds along the arterial are greater than thirty miles per hour are considered level of service A.

The next step is to calculate the arterial running speed. The arterial running speed is based on the free flow speed, the length of segment the running time per mile, and the total intersection approach delay, and is calculated using the following formula:

$$\text{ART SPD} = [(3600) \times (\text{length})] / \\ [(\text{running time per mile}) \times (\text{length}) + \\ (\text{total intersection approach delay})]$$

where

ART SPD = segment average travel speed (mph)

length = segment length (miles)

running time per mile = total running time per mile on all  
segments (sec), obtained from (Ref. 22, Table 11-4)

total intersection approach delay = total approach delay at  
signalized intersections.

For our base condition, which does not include driveway or minor street conflicts, the following numbers are used. The previously selected segment length was 0.25 mi. From (Ref. 22, Table 11-4) the running time per mile is found to be 120 sec. The total intersection approach delay will be zero in this study based on the assumption described earlier that the g/C ratio for all signalized intersections along the arterial will be equal to one. Entering these values into the formula yields the following results.

$$\text{ART SPD} = [(3600) \times (0.25)] / [(120) \times (0.25) + 0]$$

$$\text{ART SPD} = 30.0 \text{ mph}$$

This value is the average travel speed on a selected segment. This value will be used as a base condition, for ideal circumstances. As the effects of higher volumes and increasing number of conflict points are factored into the study, the average travel speed will decrease and subsequently delays will result.

The various parameters which will be held constant, and those which will be varied were depicted earlier in Table 5.1. The analyses will proceed as follows. A series of examples consisting of before/after scenarios will be analyzed. In each example, a segment of arterial will be assigned values for the parameters that will remain constant in that example. Also, for that example, constant values representing existing conditions of number of lanes, access point density (number of driveways and minor intersections), and traffic volume will be assigned. The segment will then be analyzed as an existing scenario. Each access point will be treated as an

unsignalized intersection with the method of traffic control assumed to be a stop sign on the minor street or driveway. The analysis will include the delay effects caused by vehicles executing right turns into the driveways and minor streets, and the effect of weaving caused by traffic entering the arterial from the access points. The result of this analysis of the before collector-distributor system scenario will be a measure of total delay incurred by vehicles along the segment. Effects to traffic flow on minor streets and in driveways is beyond consideration in this report, as the primary consideration is improved operating characteristics for the arterial. Certainly, though, implementing certain recommendations such as increasing geometric standards will also positively impact driveway and minor street operations.

The final step in each example will be to change the parameters which would be affected by the implementation of a collector-distributor system. An analysis similar to the before implementation scenario will be performed on this after implementation scenario. The results of these analyses will be comparison of total delay to vehicles on the arterial before and after implementation for each example.

Table 5.2 provides an explanation of the parameters that will be varied between the examples. Table 5.3 then describes the actual parameters used in each of the six example scenarios for which analyses were performed.

TABLE 5.2 EXPLANATION OF PARAMETERS THAT WILL VARY BETWEEN EXAMPLES

---

<u>Number of lanes</u> - will vary from 2 to 4 (in one direction)	
<u>Access points per mile</u> -	
low	4
medium	20
high	52
<u>Volume (per hour per lane)</u> -	
low	240
medium	600
high	1800

---

TABLE 5.3 PARAMETERS USED IN EACH EXAMPLE

Access Point			
<u>Example No.</u>	<u>No. of Lanes</u>	<u>Density</u>	<u>Volume Level</u>
1	2	medium	medium
2	3	medium	medium
3	4	medium	medium
4		low	low
5	3	medium	high
6	3	high	high

#### **Effect of Turning-Path Geometrics**

Enhancing the horizontal and vertical alignment characteristics for driveways and other access points would permit right-turning vehicles to maintain higher speeds during turn maneuvers. This would result in a modest saving in travel time to turning vehicles, but a much more significant savings to following vehicles forced to undergo a speed change cycle consisting of deceleration followed by acceleration to an initial speed. Assuming comfortable constant deceleration and acceleration rates of 8.5 and 3.1 feet per second squared (see Table 4.1 and accompanying discussion in Chapter 4), times for deceleration and cycles of acceleration and deceleration were computed. Since these times are linear functions of initial and final speeds, calculation of the changes in them for different initial and final speeds was easily done. The time a vehicle needs to travel the same distance at the average travel speed is subtracted from the sum of the acceleration and deceleration times. The resulting time is the number of excess seconds taken by the deceleration / acceleration maneuver. This time is multiplied by the hourly number of right-turning vehicles and the resulting time is multiplied by the number of intersections to obtain the total delay in seconds caused by all vehicles along that segment for an hour. The calculations were performed for a before and after implementation scenario for each example. Other assumptions made in these analyses include the following. The percentage of right-turning vehicles is one percent of the total traffic volume. The comfortable turning speed for before

implementation conditions is taken to be six miles per hour, and for after conditions it is assumed to be twelve miles per hour. These numbers are representative values based on typical existing conditions for the former and on the recommended design standards in Chapter 4 for the latter.

The results of these calculations are presented in Table 5.4. The same calculations were performed for the before-implementation and after-implementation scenario so that the results could be compared directly. Figure 5.1 presents, in graphic form, the potential delay savings due to increased right-turn speeds for both turning and following vehicles. The abscissa of this chart presents the reduction in the magnitude of speed change provided by enhanced vertical and horizontal alignment for an access point such as a driveway. That is, if turning vehicles had to reduce their speeds to 10 feet per second under existing driveway conditions, but enhanced geometrics permit a turning speed of 16 feet per second, this would represent a 6 feet per second reduction in speed change on the abscissa of Figure 5.1. Using the assumed acceleration and deceleration values, this magnitude of speed change reduction would save about 0.7 seconds during deceleration for the turning vehicle and about 2.7 seconds in speed change cycle time for a following vehicle. The chart permits easy estimation of the travel time savings for any speed change reduction.

#### **Access Point Limitation**

Reduction in the number of access points can have a significant positive impact on delay reduction. In the preceding analysis of delay reduction, results were presented in Table 5.4 based on improved turning speeds. Table 5.5 presents the results of the after-implementation scenario with two additional columns added. The first additional column contains revised values for number of access points. This reduction represents possible elimination of access points by methods recommended in Chapters 3 and 4. The final column in the after-implementation scenario represents total hourly delay along the segment after the number of access points are reduced and the geometric standards of the remaining access points are improved as per the recommendations in Chapter 4. By direct comparison of the last columns for the before-implementation scenario and after-implementation scenario, a considerable reduction in delay for each example can be observed.

Another effect on arterial operations that reducing the number of access points has, is an increase in length of weaving area which can minimize the adverse effects weaving may have on traffic flow.

**TABLE 5.4 RESULTS OF ARTERIAL RIGHT TURN DELAY ANALYSIS**

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***Before Implementation of Collector - Distributor Lane and Enhanced Driveway Geometrics***

<u>Example</u>	<u>Rt. turn vol. (vph)</u>	<u>Total hourly delay per drive (sec)</u>	<u>No. access points per segment</u>	<u>Total hourly delay per segment (sec)</u>
1	12	74.88	5	374.40
2	18	112.32	5	561.60
3	24	149.76	5	745.50
4	7	43.68	1	43.68
5	54	336.96	5	1684.80
6	54	336.06	13	4380.48

deceleration time = 2.82 sec  
 acceleration time = 7.74 sec  
 time required for through traffic = 4.32 sec  
 right turning speed = 6 mph

***After Implementation of Collector - Distributor Lane and Enhanced Driveway Geometrics***

<u>Example</u>	<u>Rt. turn vol. (vph)</u>	<u>Total hourly delay per drive (sec)</u>	<u>No. access points per segment</u>	<u>Total hourly delay per segment (sec)</u>
1	12	49.74	5	48.70
2	18	74.61	5	373.05
3	24	99.48	5	497.40
4	7	29.02	1	29.02
5	54	149.22	5	746.10
6	54	149.22	13	1939.86

deceleration time = 2.12 sec  
 acceleration time = 5.81 sec  
 time required for through traffic = 3.79 sec  
 right turning speed = 12 mph

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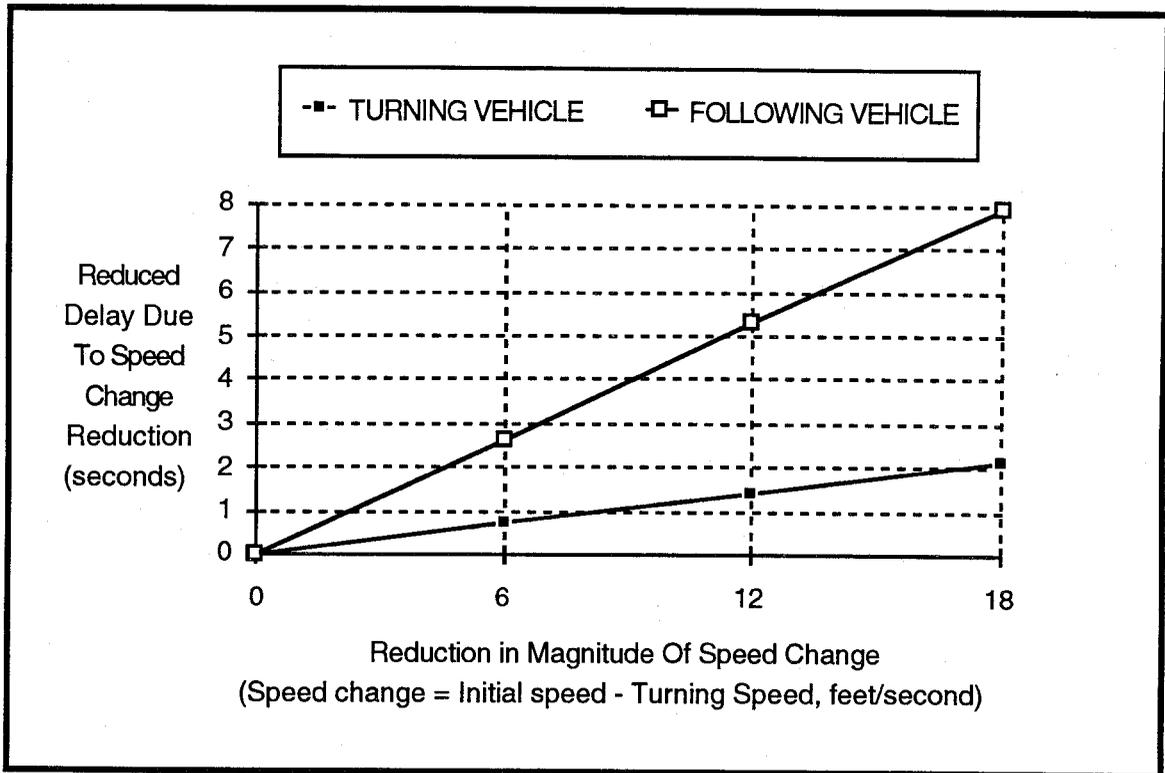


Figure 5.1. Potential delay savings due to increased right-turn speeds for turning and following vehicles.

The next set of analyses performed are weaving-area analyses. Weaving will result as vehicles turning onto the arterial merge into through lanes while vehicles in through lanes that wish to turn off the arterial merge into the right-most lane. Figure 5.2 depicts the vehicle movements which combine to create a weaving situation. Table 5.6 lists the parameters that affect weaving-area operation and are required for a weaving area analysis. The length of the weaving area is taken as the distance between consecutive driveways since it is desirable from the drivers' viewpoint to merge into through lanes immediately after turning onto the arterial and remain in the through lanes until another right-turn maneuver must be performed. The examples are calculated for the same parameters as for the right-turn delay analyses. Again the reader is referred to Table 5.3.

TABLE 5.5 RESULTS OF ARTERIAL RIGHT TURN DELAY ANALYSIS INCLUDING ENHANCED DRIVEWAY GEOMETRICS AND REDUCED NUMBER OF ACCESS POINTS

Example	Rt. turn vol. (vph)	Total hourly delay per drive (sec)	No. access points per segment	Total hourly delay per segment (sec)
1	5	248.70	3	149.22
2	5	373.05	4	298.44
3	5	497.40	4	397.92
4	1	29.02	1	29.02
5	5	746.10	4	596.88
6	13	1939.86	8	1193.76

deceleration time = 2.12 sec  
 acceleration time = 5.81 sec  
 time required for through traffic = 3.79 sec  
 right turning speed = 12 mph

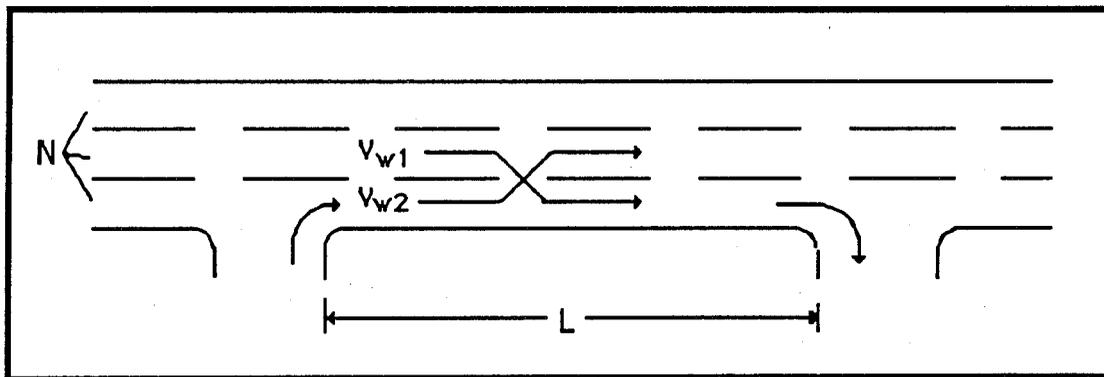


Figure 5.2 Depiction of a weaving area.

TABLE 5.6 PARAMETERS AFFECTING WEAVING AREA OPERATION. (REF. 22)

SYMBOL	DEFINITION
L.....	Length of weaving area, in ft.
LH.....	Length of weaving area, in hundreds of ft.
N.....	Total number of lanes in the weaving area.
N <sub>w</sub> .....	Number of lanes used by weaving vehicles.
NNW.....	Number of lanes used by nonweaving vehicles.
v.....	Total flow rate in weaving area.
vw.....	Total weaving flow rate.
vw1.....	Larger of the two weaving flow rates.
vw2.....	Smaller of the two weaving flow rates.
vnw.....	Total nonweaving flow rate in weaving area.
VR.....	Volume ratio, vw/v.
R.....	Weaving ratio, vw2/vw.
S <sub>w</sub> .....	Average running speed of weaving vehicles, mph.
S <sub>nw</sub> .....	Average running speed of nonweaving vehicles, mph.

The values for the parameters in Table 5.6, with the exceptions of N<sub>w</sub>, S<sub>w</sub>, and S<sub>nw</sub> which must be calculated, are determined for each example, from stated assumptions and the information presented in Tables 5.2 and 5.3. N<sub>w</sub> is a parameter which is used to determine whether the weaving area is constrained or unconstrained, and is calculated by the following formula:

$$N_w = 2.19 N V R^{0.571} L_H^{0.234} / S_w^{0.438}$$

The actual theory behind weaving area analysis and the development of the formulas used in the analyses are beyond the scope of this report. The procedures followed in these analyses were taken from the *1985 Highway Capacity Manual* (Ref. 22).

The two parameters which are relevant to the analysis of collector-distributor lanes is  $S_w$ , the average running speed of vehicles in the weaving area, and  $S_{nw}$ , the average running speed of non-weaving vehicles in the weaving area. The formulas used in the calculation of these parameters are given below.

$$S_w = 15 + \frac{50}{1 + 0.226(1+YR)^{2.2} (V/N)^{1.00} / L^{0.90}}$$

$$S_{nw} = 15 + \frac{50}{1 + 0.020(1+YR)^{4.0} (V/N)^{1.30} / L^{1.00}}$$

A listing of the values of the parameters used in each example and the results of the weaving area analyses are presented in Table 5.7

When the numbers for average running speed for weaving and non-weaving vehicles are examined, it is found that they are all comfortably above the arterial average running speed calculated at the beginning of the entire analysis, with the only exceptions being the average running speed for weaving vehicles in Examples 5 and 6, and the average running speed for non-weaving vehicles in Example 6. When these values fall below the arterial average running speed it indicates that the weaving is having a negative impact on arterial operations. Example 5 is a situation of medium access point density which means access point spacing, and subsequently, a weaving area length of 264 feet. While this value is above the absolute recommended minimum spacing shown in Table 4.2 (Chapter 4), it is still low. This demonstrates that when volumes are high, it may be necessary to increase access point spacing so as to avoid the problem of weaving traffic having a negative effect on arterial operations. In Example 6 the problem is the same, but even more so as the access point spacing is down to 102 feet which is below the recommended minimum spacing for facilities with speeds of 30 to 35 miles per hour.

TABLE 5.7. WEAVING AREA ANALYSIS AND RESULTS

<u>VAR</u>	<u>Ex 1</u>	<u>Ex 2</u>	<u>Ex 3</u>	<u>Ex 4</u>	<u>Ex 5</u>	<u>Ex 6</u>
L	264	264	264	1320	264	102
Lh	2.64	2.64	2.64	13.2	2.64	.02
N	2	3	4	3	3	3
Nw	0.12	0.17	0.23	0.21	0.20	0.18
Nnw	2,1	3,2	4,3	3,2	3,2	3,2
v	1200	1800	2400	720	5400	5400
vw	24	36	48	14	108	108
vw1	12	18	24	7	54	54
vw2	12	18	24	7	54	54
vnw	1176	1782	2376	713	5346	5346
VR	0.02	0.02	0.02	0.02	0.02	0.02
R	0.5	0.5	0.5	0.5	0.5	0.5
Sw	40.81	40.81	40.81	60.95	28.12	21.57
Snw	52.44	52.44	52.44	64.00	35.85	25.82

The final step in the weaving area analysis is to calculate the delay caused by the weaving so as to have the same unit of measure for the effects of weaving and for the delay caused by right turning vehicles. In all situations where the average running speeds from the weaving analysis are above the arterial average running speed, it is assumed that no delay is incurred as a result of the weaving operations. For the three values that fall below the arterial average running speed of thirty miles per hour, the delay is calculated by taking the difference between the time a vehicle takes to travel through the weaving area at the arterial average running speed and the time it takes the vehicle to travel through the weaving area at the reduced nonweaving vehicle running speed or weaving vehicle running speed. This value is then multiplied by the number of vehicles performing weaving maneuvers so as to obtain delay per weaving length. Sw will be used to calculate the delay caused by weaving, since delay affects vehicles following those performing the weaving maneuvers, and the reduced weaving vehicle average running speed is the lower, and therefore critical, average running speed value. Since the weaving maneuver involves at

least two lanes, the resulting delay value for each weaving maneuver is multiplied by two. In actuality, weaving vehicles may affect all three lanes, so the delay values given may be even greater. The results of these delay calculations are presented in Table 5.8.

TABLE 5.8 TIME DELAY INCURRED BY WEAVING IN EXAMPLES 5 AND 6

<u>Example</u>	<u>Total hourly delay per weaving area (sec)</u>	<u>Number of weaving areas per segment</u>	<u>Total hourly delay per segment (sec)</u>
5	86.40	4	345.60
6	196.56	12	2358.72

As can be seen from the results, the total delay per segment is greatly affected by the number of access points. As was the case with the right-turn analysis, delays at individual driveways may or may not be unreasonable, however, as the number of points of access increases, the delay incurred increases proportionally. In situations where volumes become very high, it is recommended that access points be spaced as far as practicable. Reducing the number of access points to sixteen per mile in both Examples 5 and 6, increases the average running speed of weaving vehicles to a value greater than the arterial average running speed and subsequently the delay incurred by weaving maneuvers drops to zero. In addition, the delay values calculated both for the weaving analysis and the right-turn delay analysis, are delays incurred by only one following vehicle per maneuver. In cases where traffic volumes are high, the delays may effect several following vehicles at once, increasing the total delay on a segment by as many times as there are vehicles upon which delay is incurred.

### **Eliminating Left-Turn Opportunities By Means of a Continuous Median**

Perhaps the most significant benefit to arterial operations will occur when all turning movements, including left turns, are made from the collector-distributor lane. A continuous raised median prevents undesirable left turns at points between major intersections. Unfortunately, this concentrates left-turn movements at the major intersections which may present a capacity constraint at those intersections. In addition, left-turn movements create friction to left-most through-traffic lanes. If all turning movements are made from the collector-distributor lane, the left lanes can be completely reserved for through traffic. The benefits of doing this can be seen quite readily. In the best case, when left turns are made from the left lane, a left-turn bay will be provided at major intersections. However, the existence of this left-turn bay creates a weaving area to the left with similar negative effects as the weaving areas previously analyzed. In addition, the left-turn lane imparts friction to the through traffic and decreases the drivers perception of security resulting in slower through traffic operating speeds. In the worst case, no left-turn bay is provided and left-turning vehicles must stop in through-traffic lanes. The negative impacts this has on arterial operations are enormous. By forcing all turning movements to be performed from one side of the road, the left-most lanes can be reserved entirely for higher-speed, through-travelling vehicles, and the function of the collector-distributor system begins to resemble that of collector-distributor streets on freeways.

Ideally, major intersections would be grade separated and turning movements would be facilitated by the appropriate interchange roadways. At most existing major intersections there is a lack of sufficient right-of-way to construct these facilities. Where turning volumes are low enough, left turns could be replaced by a series of right turns through the local street network. As turning volumes increase, however, the benefits to the arterial may be offset by the detrimental effects caused by the additional volume on the surrounding streets. An intermediate solution might be the construction of turning roadways or 'jug handles' which channel vehicles wishing to turn left, from the collector-distributor lane to the cross street, from which they could make the desired turns. Again, these facilities require right-of-way which may not be available. If left turns can be eliminated from the arterial for long enough distances, the construction of grade separations or turning roadways at major intersections may be justified. Strictly based on the objective of improving arterial operations, any method for allowing all turning movements to be performed from the collector-distributor lane would be beneficial.

## SUMMARY OF RESULTS AND CONCLUSIONS

In this chapter several examples were generated to demonstrate the possible effects of implementing a collector-distributor lane on an arterial street. Each example presented a different combination of access-point density, number of lanes, and traffic volume. As a summary of the results of the various analyses, Table 5.9 presents a comparison of estimated total delay that might be incurred on example segments before and after the implementation of a collector-distributor lane.

TABLE 5.9 COMPARISON OF BEFORE/AFTER RESULTS

<u>Example</u>	<u>Total delay incurred before implementation (seconds)</u>	<u>Total delay incurred after implementation (seconds)</u>
1	374.40	149.22
2	561.60	298.44
3	745.50	397.92
4	43.68	29.02
5	2030.40	895.32
6	6379.20	1790.64

The delay values reported in Table 5.9 are the summation of delays incurred by both right-turning vehicles and by weaving maneuvers. It is evident that the implementation of the recommendations of Chapters 3 and 4 can have a significant impact on delay reduction. It should also be noted that these delays are for a segment which was defined earlier in these analyses as one-quarter mile long. The delay incurred on a one-mile segment in one hour based on the conditions for each example is therefore four times the delay figures shown in Table 5.9. The above examples were designed to provide a range of combinations of arterial characteristics and were used to demonstrate the possible effects of collector-distributor system implementation within those scenarios.

The decision to implement a collector-distributor system on an arterial street must consider many variables. The purpose of this report was to recommend various improvements that can be incorporated into the implementation of a collector-distributor system, and then to evaluate the potential improvements that might result from the implementation. Not every arterial street warrants the implementation of a collector-distributor system. Certainly, individual recommendations made in Chapters 3 and 4 will have marginal benefits when implemented by themselves. The engineers and policymakers involved in the decision process must consider the many variables presented in this report before deciding on a course of action. From the results presented in this chapter, it can be seen that, given the appropriate combination of conditions, the implementation of a collector-distributor system on an arterial street may be an effective measure in improving the operational characteristics of that arterial.

## CHAPTER 6

### SUMMARY AND RECOMMENDATIONS

The purpose of this report was to explore various methods for improving arterial operations. Appropriate methods could be applied to create a collector-distributor system that would function similarly to a collector-distributor road serving a freeway. It was considered extremely important that the techniques that were examined could provide significant improvement to arterial operations while still remaining cost effective and practicable.

In the first chapter of this report, current issues in highway network mobility are discussed, and the need for cost effective measures to improve operations along highly-developed arterial street is identified. The concept of a collector-distributor lane is introduced as one possible way of alleviating some of these problems

In the second chapter, the results of a literature review to determine to what extent, if at all, the issue of collector-distributor lanes had been previously addressed, are presented. Summaries were provided for some of the literature related to this study. The works were divided into categories including access control, geometric design, capacity analyses and weaving areas, safety, and general references.

Chapter 3 addresses the control of access as a technique for improving arterial operations. The conflict between mobility and access is described and objectives for establishing control of access are discussed. Various methods, both legal and technical, are explored and recommendations are made. These recommendations include limiting numbers of access points and establishing minimum spacing requirements. To minimize vehicular friction between the collector-distributor lane and the through lanes, minimum lane widths are recommended. Finally, appropriate delineation and markings for the collector-distributor lane are discussed.

Chapter 4 addresses methods of eliminating access points and improving their geometric design. The goal of this chapter is to provide recommended standards that can improve driveway and intersection operations, particularly by reducing delays caused by turning movements.

In Chapter 5 the ideas discussed in Chapters 3 and 4 are incorporated into a collector-distributor system concept. This system would include limited arterial access, improved access-point geometric standards, a physical median separation to limit left-turn opportunities from through traffic lanes, and finally, the appropriately delineated collector-distributor lane. The improvements to arterial operations, measured in terms of reduction in delay, are quantitatively evaluated for the recommended techniques by means of six case study scenarios. The chapter

concludes by noting that with careful consideration of existing conditions, implementation of a collector-distributor system may provide effective means for reducing delay along an arterial street.

This report presents a compilation of various techniques for implementing a collector-distributor system and an evaluation of the effectiveness of those techniques. Of course, the most accurate way of measuring the impact of collector-distributor system implementation is by applying the methods recommended in this report and then collecting and evaluating before-and-after field data. The author recognizes the importance of actual application of the recommended methods and evaluation based on observed improvements to arterial operations, and suggests that this topic warrants further investigation.

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