HIGH-OCCUPANCY VEHICLE PRIORITY TREATMENTS ON SUBURBAN ARTERIAL STREETS

by

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SUMMARY

In an attempt to combat the growing problem of traffic congestion in urban and suburban areas, many priority treatments have been implemented for high-occupancy vehicles (HOVs) on freeway facilities. These HOV priority treatments have provided travel time savings and reliability to carpools, vanpools, and public transit vehicles. Much of the current emphasis has been on freeway HOV facilities, with little consideration of the application of priority treatments on arterial streets, especially in suburban areas. The majority of past or existing arterial street HOV facilities have been bus-only lanes in the central business district. This report contains a discussion of the major issues regarding the planning and operation of HOV priority treatments on suburban arterial streets.

Planning Issues

The integration of arterial street and freeway HOV facilities in a regionwide HOV system plan provides regional mobility for HOVs and maintains or extends travel time savings over a longer portion of the trip. An integrated HOV system would ideally provide priority treatment during the line-haul portion of an HOV trip, as well as the collection and distribution stages.

There are several consequential elements that should be considered in the assessment of conceptual viability of an arterial street HOV facility. The presence of severe and recurring congestion, typically defined as level of service E or F by most agencies, is necessary for acceptable minimum utilization. A travel time savings, as well as trip time reliability, must be available as an incentive to divert existing HOV traffic and encourage formation of new carpools. Agency, employer, and public support play a large role in the implementation and successful operation of any HOV facility, especially one on arterial streets. Large employers at suburban activity centers can be a major impetus in the formation of transportation demand management programs that encourage and support the HOV concept.

The physical characteristics of an arterial street may limit the feasibility or choice of priority treatments. The presence of medians, curb parking lanes, or shoulder right-of-way present more opportunities for HOV facilities than with their absence. Because an arterial street has considerably more conflicting activities than a freeway environment, safety is a larger concern on these HOV facilities. Turning movements, loading and unloading of transit buses, and activities associated with bicycles and pedestrians all conflict with the objective of uninterrupted throughput on an HOV lane.

Operation Issues

There are several different alternatives for priority treatment of HOVs on arterial streets. Arterial operation alternatives refer to lane treatments along the length of the arterial, while signalized intersection operation alternatives refer to priority treatments at signalized intersections. The feasibility of each of these different alternatives is determined by site-specific conditions like area location, arterial geometry, HOV and mixed-flow traffic

volumes and distributions, public and political acceptance, and other factors. The combination of arterial and signalized intersection operation alternatives is desirable, and often necessary, for continuous, unimpeded flow along an arterial.

The foremost objective in determination of occupancy restrictions for vehicle/user eligibility is maintenance of person-carrying capacity of the HOV facility. This may entail switching the occupancy restrictions from two or more persons per vehicle to three or more persons per vehicle, or three or more persons per vehicle to four or more persons per vehicle, etc. The use of HOV facilities by other vehicles should be determined on a case-by-case basis, where the benefits of HOV lane use are weighed against disadvantages like negative public perception or inefficiency. Similarly, the hours of operation of an HOV facility may be determined according to traffic and lane operational characteristics. Reserved HOV use during the peak period only has been the most widely used method of operation on arterial streets, and is more publicly acceptable than typically underutilized continuous operation.

Enforcement is perhaps the largest existing implementation barrier for HOV priority treatments on suburban arterial streets. There are several enforcement techniques currently being used or developed on freeway HOV facilities that may be directly transferrable to arterial streets. Self-enforcement techniques, like the HERO hotline program on Seattle area freeways, allows frustrated motorists to report HOV violators, who consequently receive warnings and possibly tickets through the mail. Other techniques that incorporate video cameras and image recognition systems also hold a promise for the lower speeds on arterial street HOV facilities.

Support facilities and programs play an essential role in a regionwide HOV system. Preferential parking and other parking demand management techniques can be very effective in encouraging ridesharing at suburban employment centers. Other transportation demand management actions, like flexible work hours and commuter matching services, can also serve as important support programs. The involvement of large suburban employers in HOV support programs helps to bolster support and build a constituency for the HOV concept in suburban areas.

Recommendations

The literature review performed in this study found a lack of documentation on HOV priority treatments on suburban arterial streets. Although operation and design guidelines do exist for bus facilities in urban arterial settings, few comprehensive references were located that related to all traditional HOVs on suburban arterial streets. Further research would ideally provide a comprehensive documentation of arterial street experience, assess arterial street HOV projects to identify desirable design and operation guidelines, and develop a methodology for assessing the effectiveness of future arterial street HOV facilities.

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INTRODUCTION

Problem of Traffic Congestion

Traffic congestion, once only a problem in the central business district, has become a daily reality for residents and commuters in urban and suburban areas. Congestion in downtown areas and on urban highways and streets has increased to the point where the morning and evening "rush hour" now each extend over several hours, and sometimes even through midday. This rapid increase in traffic congestion over the past decade has become a major concern of transportation professionals, policy-makers, business communities, environmentalists, and the general public.

Several elements have contributed to the rapid growth of traffic congestion in the United States in recent years (1). The number of registered vehicles has increased disproportionately to the population and household growth; in turn, vehicle travel has spiraled to over 3.2 trillion vehicle-kilometers (2 trillion vehicle-miles) by the late 1980s. To compound the increase in travel, construction of new highway facilities has slowed considerably since the near completion of the Interstate System in the early 1970s. A higher percentage of commuters now drive a single-occupant vehicle instead of carpooling or using public transit because of increased access to the automobile and less intense suburban development. The dramatic increase of congestion in suburban areas has been partially attributed to the development of suburban activity centers outside of the central business district. The migration of major employers and businesses to these activity centers has, in effect, created sprawling but somewhat intense development without the necessary supporting transportation infrastructure.

High-Occupancy Vehicle Priority Treatments

Various management techniques have been applied in an attempt to alleviate traffic congestion. These techniques may be broadly categorized as either transportation systems management (TSM) or transportation demand management (TDM) actions. One of the most successful TSM actions in recent years has been the priority treatment of high-occupancy vehicles (HOVs). The priority treatments have typically been either the provision of dedicated through-travel lanes or queue bypass lanes at roadway capacity restrictions. Through the use of priority measures, HOVs (buses, vanpools, and carpools) are given two significant advantages: travel time savings and trip time reliability. These two benefits are the primary incentives used to encourage a shift from the single-occupant vehicle to the ridesharing and public transit modes.

Objectives

The priority treatment of HOVs has several objectives: induce a modal shift, increase the person-carrying capacity of highway corridors, reduce total travel time, reduce or defer the need to increase highway vehicular capacity, improve the efficiency and economy of public transit operations, and reduce fuel consumption (2). More recently, the improvement of air quality along dense travel corridors (pursuant to the Clean Air Act

Amendments of 1990) has been a consideration in implementation of HOV facilities. In addition, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 restricts federal funding on transportation improvements that solely increase vehicular capacity (3). Under the Interstate Maintenance program of the new Act, however, HOV lanes may receive this funding.

Freeway HOV Facilities

Much of the current research, funding, and application of HOV treatments has been devoted almost exclusively to freeways and other uninterrupted flow facilities. The line-haul travel, long trips, and limited access of these facilities are particularly suited for implementation of HOV lanes. Increasing congestion and decreasing mobility on urban highways has also been a major impetus in the development of HOV programs. The major impetus for freeway HOV facilities in North America occurred between 1969 and 1970 with the implementation of the Shirley Highway (I-66) exclusive bus lanes in the Northern Virginia/Washington, D.C. area, and the Lincoln Tunnel (Route 495) contraflow bus lanes in New York City. As of April 1990, there were over 534 kilometers (332 miles) of HOV lanes in operation on freeways or in separate rights-of-way in North America (4). This mileage represents 40 different HOV facilities operating in 20 different metropolitan areas.

Arterial Street HOV Facilities

The current experience with HOV facilities on arterial streets has been limited compared to those on freeways. The majority of arterial street HOV facilities have been bus-only lanes located in the downtown or central business district (CBD) area. An earlier study located the first arterial street bus-only facility on North Sheridan Road in Chicago in 1939, and identified 40 other similar arterial bus-only priority projects (5). Few significant arterial street HOV projects have been initiated since the mid-1970s energy crisis, and many have since been suspended for a variety of reasons ranging from low utilization to enforcement problems (6). Very few of these projects have permitted the operation of carpools or been located in a suburban environment.

Increasing congestion at suburban activity centers, recent successes of freeway HOV facilities, and increased political pressure have prompted an awareness of the need for arterial street HOV facilities that permit carpools and vanpools as well as buses. Many transportation professionals, however, have noted the absence of guidelines for HOV facilities on arterial streets. This report attempts to address the major issues regarding the planning and operation of HOV priority treatments on suburban arterial streets. The focus of the report is arterial streets in suburban environments, with carpools constituting a representative percentage of the HOVs. An earlier report, *Bus Use of Highways*, provides excellent planning and design guidelines for bus-only priority treatments in CBD areas (7).

Distinctions Between Arterial Street and Freeway HOV Facilities

The representative design of a freeway HOV facility cannot simply be copied into an arterial street environment. There are several functional and operational characteristics that prevent the freeway experience from being directly transferrable to arterial street HOV facilities. The principal source of congestion on arterial streets is at signalized intersections, where queues form and considerable delay may be experienced. The speeds on arterial streets are lower than on freeways, access is not controlled to the same extent as on freeways, and trip length is customarily shorter on arterial streets. Travel, in general, is more dispersed on arterial streets, where vehicles may exit at every curb cut as opposed to every exit ramp. The arterial street environment is also complicated by a variety of activities, from bicycle, pedestrian and turning movements to loading and unloading of public transit buses.

Organization of the Report

This report contains a discussion of the major issues involved in the implementation of HOV priority treatments on suburban arterial streets. The report body is organized into two major sections: planning and operation issues. The section on planning issues presents a generic HOV planning process, with specific elements applicable to arterial streets discussed in detail. The section on operation issues presents and discusses the various operational alternatives for arterial street HOV facilities, and the particular situations where the various alternatives may be best suited. The major conclusions of this study are summarized in the findings section. Specific recommendations regarding the research and application of arterial street HOV priority treatments are presented in the final section.

PLANNING ISSUES

The HOV planning process that has been developed for freeway facilities can be applied in general terms to arterial streets. This common planning process consists of four primary steps: 1) assessing the conceptual viability of any HOV priority treatment, 2) identifying and evaluating the various preliminary alternatives, 3) developing the feasible alternatives, and 4) adoption of an acceptable plan (2). An HOV planning process in the context of suburban arterial streets is briefly discussed in this section, with emphasis given to critical elements of arterial street HOV planning.

Regionwide HOV System Planning

Although most HOV projects are implemented on a corridor basis, the importance of regional HOV system planning has been stressed for the past several years; consequently, many transportation agencies have begun to prepare HOV system plans for major metropolitan areas. For example, the California Department of Transportation (Caltrans) has drafted HOV system plans for the Los Angeles Basin, the San Francisco Bay area, San Diego, and Sacramento (8). The concept of regional HOV system planning acknowledges the interdependent relationships among the various HOV facilities and the corresponding support facilities, like park-and-pool lots and off-line transit stations, throughout a metropolitan area. Historically, however, arterial street HOV facilities have not been considered feasible to be included in HOV system plans.

The integration of arterial street HOV facilities and freeway HOV facilities is the next logical step in regionwide HOV system planning. Freeway HOV facilities primarily serve longer distance line-haul trips, and infrequently serve the distribution stage of a trip. The average commuter trip, however, includes the distribution, collection and access stages. Around major activity centers, these latter stages of the trip are served by principal and minor arterial streets. If these arterial streets are as congested as the freeway general-purpose lanes, the two main incentives for HOVs -- travel time savings and reliability -- are lost. Just as support facilities are vital in freeway HOV system plans, arterial street HOV facilities may serve an essential role in distributing freeway HOV traffic and extending or maintaining travel time savings on arterial streets.

Arterial street HOV facilities, when incorporated into transit system plans, can significantly improve bus operations. Express bus routes operating between suburban areas and the CBD may be able to provide quicker, more efficient service when operating in freeway and arterial street HOV priority lanes. Past experience with bus operations on priority lanes in downtown and CBD areas has demonstrated schedule reliability and increased transit use.

This, however, is not to deny the importance of isolated HOV priority treatments on arterial streets. Because signalized intersections are often the most visible source of delay, HOV queue bypass lanes or priority treatment at individual intersections can be both simple and cost-effective.

Assessment of Conceptual Viability

The first step of the HOV planning process is assessment of the conceptual viability of any HOV project. Also referred to as the fatal flaw analysis, this step checks the corridor characteristics against a list of criteria developed from previous HOV experiences. If the corridor does not meet the criteria, it is unlikely that an HOV facility in that corridor will be successful. The following paragraphs contain a discussion of several criteria conducive for the implementation of HOV facilities on suburban arterial streets.

Congestion

Effective operation of HOV priority treatments on arterial streets favors traffic conditions with severe and recurring congestion. Although a universal definition of congestion has not been agreed upon, most metropolitan area agencies designate congestion as traffic operating at either level of service (LOS) E or F, which is comparable to average travel speeds below 25 kilometers per hour (10 miles per hour) on arterial streets (9). At signalized intersections, this equates to an average stopped delay greater than 40 to 60 seconds (some agencies use roughly one cycle length).

Travel Time Savings

Experience with freeway HOV facilities has demonstrated that a travel time savings of between five and seven minutes is necessary to induce a mode shift. Although little experience has been documented in this area, it is expected that a comparable travel time savings is necessary on arterial streets. Time savings of this magnitude may not be available with the shorter trips and lower travel speeds associated with arterial streets, but connection with a freeway HOV corridor lessens the importance of additional time savings. Several priority treatments at spot locations (e.g., signalized intersections) along a line-haul arterial street may have the cumulative effect of a significant time savings, and should be considered as a system of priority measures.

Minimum HOV and Person Throughput

The operation of many arterial street bus-only lanes has been suspended because of low utilization and the associated negative public perception. It is especially critical on arterial streets that the HOV flow on priority lanes meet minimum standards of usage. The opportunities for violations increase as angry motorists attempt to ride in an empty HOV lane. Local perception of acceptable lane use may vary between areas, and there has been little documentation in the literature regarding minimum acceptable HOV flows on arterial streets. In terms of person throughput and overall efficiency, HOV lanes in general should provide service to at least the same number of persons as in an adjacent, general-purpose lane.

Agency and Public Support

Another critical element necessary for the implementation of HOV facilities on arterial streets is agency and public support. The full cooperation of all local, regional, and state agencies is essential in the planning, design, construction, and operation stages. In a suburban environment, principal arterial streets are more likely to traverse several local jurisdictions. The potential for disagreement, confusion, and nonuniformity is very likely where HOV lanes extend through multiple jurisdictions. The concept of a lead agency, or a "champion for the HOV cause," has been a major factor in implementation of freeway HOV facilities, and would certainly apply in the case of arterial street HOV facilities (10). A project management team could also help to coordinate multi-agency efforts, identify and assign specific project responsibilities to individual agencies, and eliminate inherent communication problems.

Public and political acceptance is often the pivotal element for HOV facilities that provide marginal service. Education and marketing of the HOV concept are important instruments in developing a public constituency. Public outreach, meetings and hearings, and other means of public participation should form the basis for a sound and effective public support program.

Enforceability

One of the largest obstacles to including carpools on many of the arterial street bus-only lanes has been enforcement problems. The busy arterial street environment with its many different activities is one of the hardest to enforce compliance with HOV restrictions. The feasible HOV operation alternatives on arterial streets do not provide as great or as distinct a physical separation of HOV and mixed-flow traffic as those priority treatments on freeways. For instance, the use of barriers or buffers on freeways to separate HOV and mixed-flow traffic lends itself well to enforcement, but is seldom appropriate on arterial streets due to lower speeds and access concerns. The next section on operation issues contains a discussion on each of the operation alternatives in detail, and provides further elaboration on enforcement problems and potential solutions.

Physical Characteristics of the Roadway

The existing characteristics and features of the arterial street govern the applicability of various HOV alternatives. Implementation of HOV facilities typically involves retrofitting designs into an already constrained right-of-way. While most freeway HOV facilities rely on the dividing median for space, only some principal arterial streets contain medians that may be used for HOV projects. More often, parking or curbside lanes are converted to HOV lanes, along with widening or expansion on the outside of the roadway. Although not popular with other motorists, some arterial street HOV projects have taken a general-purpose lane out of service for HOV use. Arterial streets in urban areas are more likely to be undivided facilities and have a constrained right-of-way, while suburban arterial streets are typically less constrained by the presence of a dividing median.

Safety

The safety of motorists and pedestrians should be a prime consideration in the assessment of any HOV priority treatment. Pedestrians are not considered in most freeway treatments, but the increased access and curbside activity of arterial streets warrant specific attention to pedestrian safety. As mentioned with enforcement problems, HOVs on arterial streets are typically not separated by barriers or buffers; consequently, conflicting movements and speed differentials increase the potential for accidents on arterial street HOV lanes. As a general goal, the number of accidents within the HOV envelope should be held to less than that occurring in the adjacent general-purpose lanes, based on a comparison of vehicle-kilometers of travel (2).

Estimation of HOV Demand

Preliminary procedures for estimating the demand for HOV facilities have been developed for freeways, but no such procedures were found in the literature for arterial streets. Data collection procedures initiated in the conceptual stages of HOV planning commonly use some type of survey instrument. A recent report describes the use of a motorist survey in a Seattle area suburb to determine commuter trip behavior on a high priority arterial targeted for HOV improvements in the Eastside Transportation Program (11). The survey consisted of questions about trip origin, destination, and purpose to gauge the residential and commercial zones serviced by the principal arterial street. This report noted the lack of data to predict the effectiveness of an arterial HOV project, and also lack of the measures of effectiveness to evaluate existing arterial HOV lanes.

In general, the HOV demand estimation procedure addresses three potential sources of demand: corridor growth, latent demand, and diversion of existing HOVs from the study route or parallel routes (2). The traffic modeling for demand forecasting is performed for a short term, typically one to two years (most doomed HOV projects will fail in this time period). Corridor growth may be estimated by factors commonly used in other local planning applications. The latent demand is best estimated using existing arterial street HOV facilities. Since very few that include carpools in a suburban setting are in operation at this time, little guidance exists for estimation of latent demand. A rule of thumb used for freeways is that latent demand can represent up to two-thirds of the forecasted demand of a new HOV facility (2). The estimation of diversion is based on primary diversion, or diversion from the study route main-lanes, and secondary diversion from parallel or adjacent streets. The percentage of HOVs that will divert mainly depends on the vehicle occupancy restrictions of the HOV facility. Again, few guidelines exist on the HOV diversion percentages for arterial streets, but for freeway purposes primary diversion is approximately 80 percent and secondary diversion is between 25 and 50 percent for each parallel route.

Alternatives Analysis

Once it has been determined that an HOV project is conceptually feasible for the corridor in question, the next step in the planning process is the identification and evaluation of all possible alternatives. The analysis of alternatives for arterial street HOV projects is much like that in a typical planning process. The various operation and design alternatives for HOV priority treatment must be considered. The geometrics (e.g., cross-section) and traffic flow characteristics (e.g., directional distribution) of the candidate corridor may eliminate some alternatives from further consideration. The alternatives are then evaluated based on their cost-effectiveness and relative design and operational merits.

Once all preliminary alternatives have been identified and evaluated, a "shortlist" is compiled of the recommended alternatives.

Development of the recommended alternatives further refines the specific operation and design criteria of each alternative. Additional consideration is given to the specific details related to each alternative, such as location and sizing of support facilities, operation of enforcement programs, hours of operation, and vehicle/user eligibility. Further refinement of the alternatives develops more detail and eventually leads to an adopted arterial street HOV plan.

OPERATION ISSUES

This section contains a discussion of the major issues regarding the operation of HOV priority treatments on arterial streets. The various types of operation alternatives are presented for arterial and signalized intersection treatment, in addition to the particular situations where each alternative may be best suited. Other operational considerations like vehicle/user eligibility, operating times, enforcement programs, and support facilities and programs are also presented and discussed.

Arterial Operation Alternatives

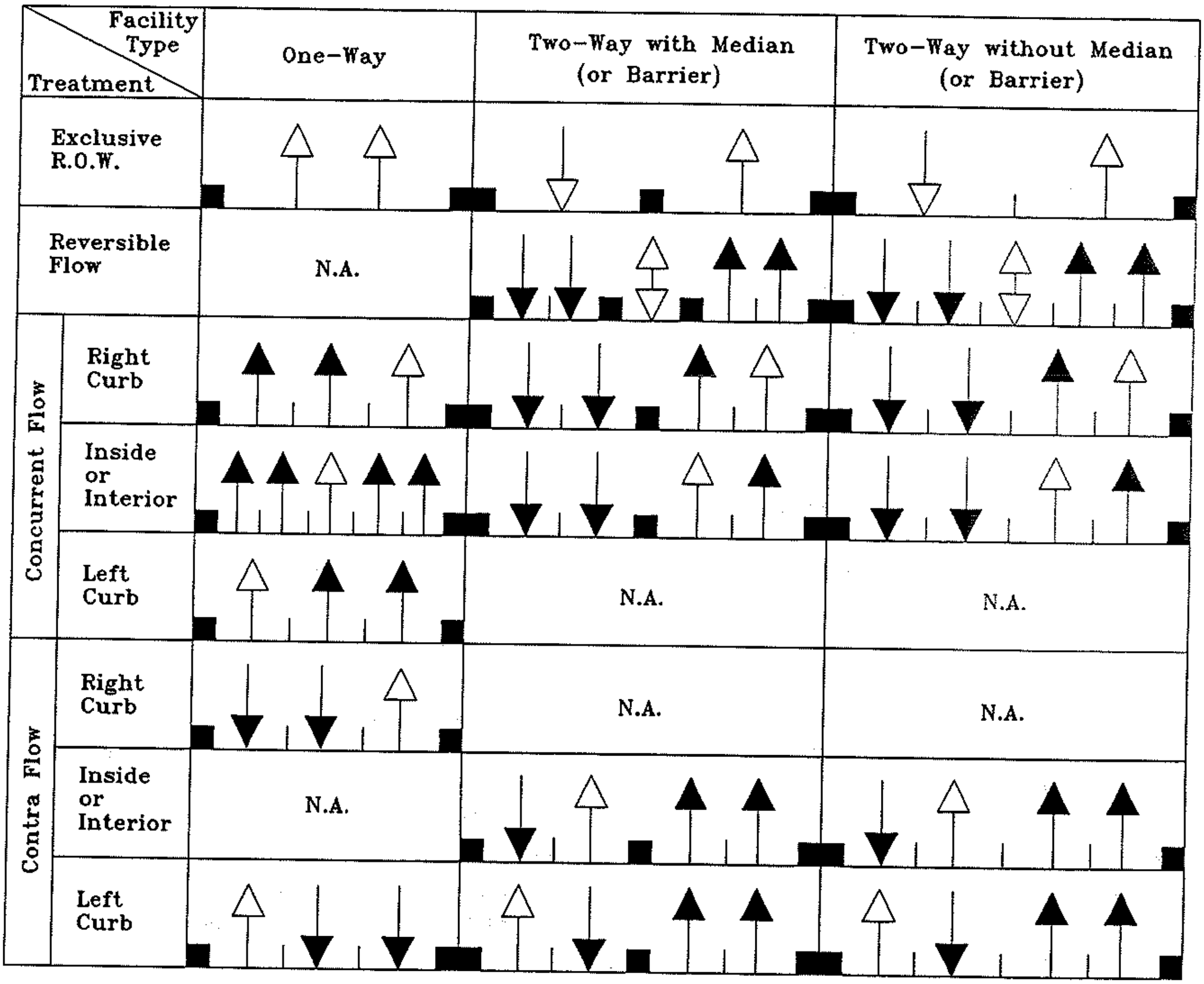
There are five basic arterial operation alternatives for HOV priority treatment: exclusive right-of-way, reversible flow, concurrent flow, contraflow, and queue bypass. Each of these arterial operation alternatives uses different lane configurations and design elements to provide a priority lane for bypassing or avoiding congestion on the link portion of arterial streets. A summary of the various arterial street HOV operation alternatives (Figure 1) follows.

Exclusive Right-of-Way (Bus Street)

An exclusive HOV facility, more commonly referred to as a bus street, is an entire segment of roadway devoted and used exclusively by HOVs. Most of these facilities have historically been oriented toward buses. Exclusive HOV facilities, like bus streets and bus tunnels, are commonly found in downtown or CBD areas where dense bus operations congest surface streets. Transit malls may also be employed where numerous bus pullouts or stops are located along an exclusive facility. The State Street Transitway in Chicago and the Chestnut Street Transitway are currently operating examples of exclusive bus facilities, albeit in CBD areas (13). Bus streets and transit malls primarily solve the problem of internal circulation, but these exclusive facilities provide little relief for line-haul congestion common on suburban arterial streets. Because development and transit operations are considerably less dense than in the CBD, exclusive HOV facilities in a suburban setting would not be warranted.

Reversible Flow

A reversible flow HOV facility consists of one or more lanes, usually barrier-separated in the median, operating in one direction in the morning and the opposite direction in the evening (Figure 1). This type of facility is used where there is a highly directional flow, like the common home-to-work trip along a radial corridor into the CBD area. Reversible flow lanes are generally warranted where the peak-hour directional split is greater than 65/35 percent.



Note: Right and left curbs, are as viewed from the HOV lane

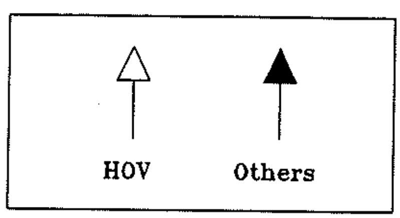


FIGURE 1. Arterial street HOV operation alternatives

Source: Table III-1, Ref. (13)

Physical separation of the HOV and opposing mixed-flow traffic is valuable for all reversible flow facilities on arterial streets. The HOV envelope provided by separation elements reduces potential conflicts, and improves the safety and efficiency of HOV and mixed-flow traffic operations. Lower vehicle speeds and an increased need for access, however, limits the usefulness of separation barriers or buffers in the arterial street environment. Barriers restrict access for HOVs to individual entrances and exits, inconveniencing or potentially excluding those HOVs entering from an intermediate cross street. The confined median space of a divided arterial street also limits the practicality of either a barrier or a buffer, both of which may consume valuable right-of-way. For these reasons, barrier or buffer separation is seldom warranted for use on suburban arterial street HOV facilities.

There are also safety concerns for buses that must unload in a median reversible flow facility. Provisions are necessary for service stops and pedestrian refuge if buses must load or unload in the median area (7). Pedestrian crosswalks and turn restrictions may also be warranted if bus patrons must cross high-speed traffic. Because express bus service may be more common than local service along suburban arterial streets, it is anticipated that off-line transit stations would be provided for median HOV facilities.

The left-turning movements at intersections introduces another problem to median reversible flow HOV lanes. A reversible flow bus lane on NW 7th Avenue in Miami, Florida, used two different solutions (14). The first configuration prohibited all left turns during the peak periods for mixed-flow traffic, but used the exclusive center lane as a continuous, two-way left turning lane during the off-peak periods (Figure 2). The other configuration incorporated special traffic signal phasing to eliminate conflicts between buses in the exclusive lane and left-turning mixed-flow traffic (Figure 3). In both cases, no physical separation was provided between the exclusive bus lanes and mixed-flow traffic.

Concurrent Flow

A concurrent flow HOV facility operates one or more lanes in the same direction of travel as the mixed-flow traffic during at least portions of the day (Figure 1). On arterial streets, the concurrent flow lane may be located either to the right (curb) or left (inside) of the general-purpose lanes. Concurrent flow freeway facilities generally use a wide paint stripe or a buffer (barriers are usually not warranted) to separate the HOV lane from the general-purpose lanes (15). However, most HOV projects on arterial streets have implemented a nonseparated concurrent flow lane, whether located on the curb-side or left-side of the general-purpose lanes. Several of these HOV projects have also used turn restrictions at signalized intersections to minimize conflicting movements.

The I-394 interim HOV lane ("Sane Lane") was used on an arterial highway in the suburbs of Minneapolis to introduce the HOV concept to commuters and increase capacity during construction of US-12 (16). Both a single reversible HOV lane and two concurrent flow lanes were used along the signalized arterial street. No turns were permitted to or from the reversible HOV lane at intersections for safety and operational reasons. The concurrent flow lane was located along the inside of the arterial, and provided access to and from the reversible HOV lane. Illegal lane-switching and turning at intersections were

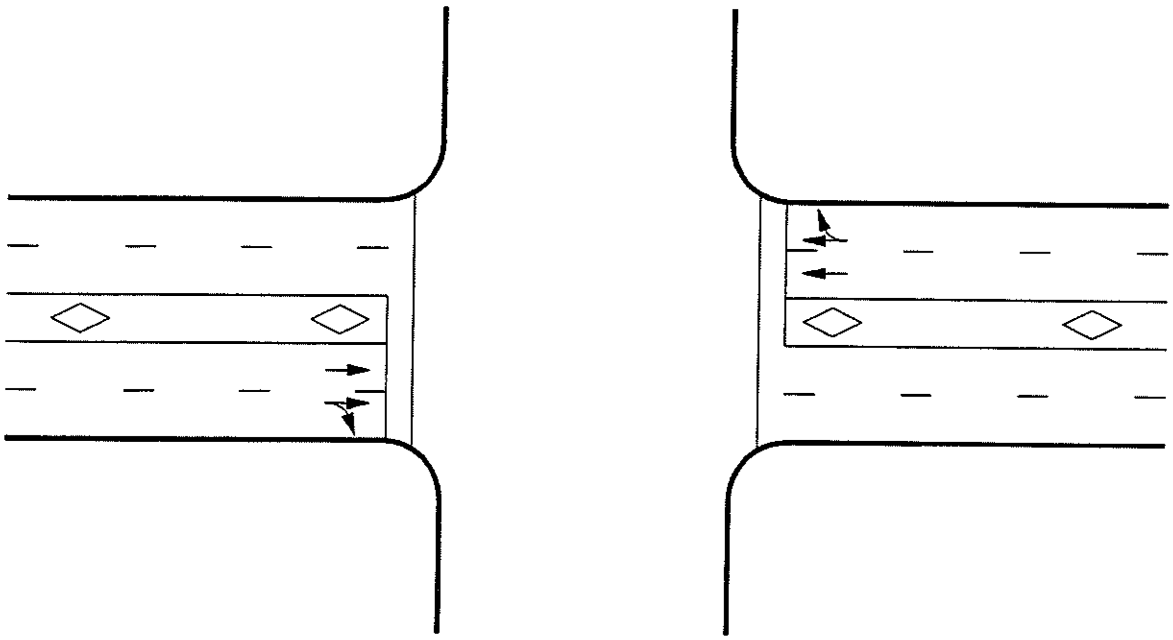


FIGURE 2. Reversible flow facility with restricted left turns

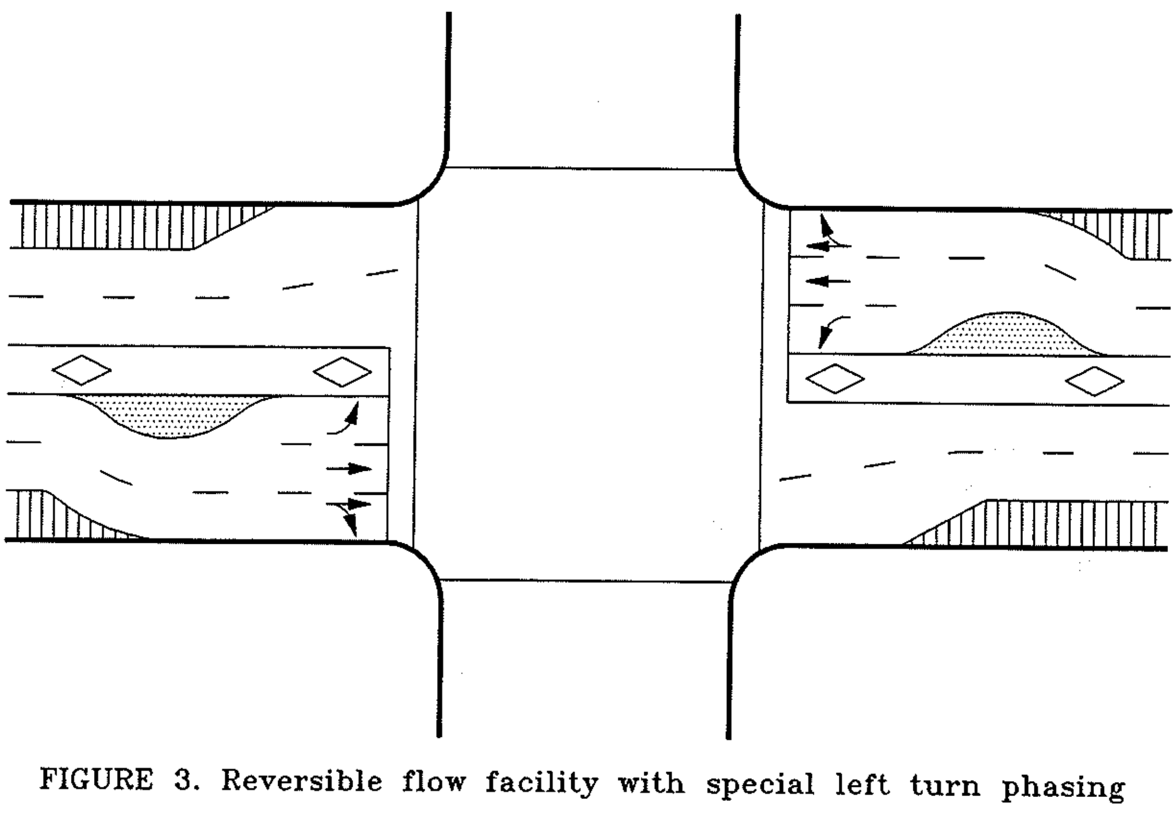


FIGURE 3. Reversible flow facility with special left turn phasing

Source: Figure 4, Ref. (5).

minimized through proper signing and enforcement, and signal timing was optimized based on the progression of traffic in the HOV lanes. A preliminary evaluation indicated that this type of project can operate successfully and safely, even during construction.

The South Dixie Highway has provided a 8.9-kilometer (5.5-mile) segment (15 signalized intersections) of concurrent flow HOV lane into the Miami CBD since 1974 (17). The left-side concurrent flow HOV lane serves both buses and carpools during the peak periods only, and left turns from the arterial street have been prohibited. Traffic signals were modified to improve progression, extend the cycle length, and reduce to two phases. Enforcement has played a large role in the relatively low violation rate of 8 percent. Initial travel time savings was between 5 and 10 minutes, and HOVs now carry about 40 percent of the total person volume on the arterial street.

Other concurrent flow alternatives exist for left-side HOV lanes that permit left turns from the arterial street. In one configuration, the left-turning traffic merges across the continuous HOV lane and into a left-turn bay (Figure 4). Another alternative incorporates an additional phase to separate the HOV through movement and the left-turning movement (Figure 5). Both of these alternatives would be suitable where high left-turning volumes and public opposition do not allow turning restrictions. Operating the HOV lane in the center of an arterial street eliminates the conflicts associated with right-turning movements and egress and ingress from driveway entries that may be encountered in the curb lane. However, left-turning movements replace right-turning movements as a problem, and additional concerns arise with regard to loading and unloading of bus passengers in the middle of an arterial street.

A concurrent flow HOV lane can also be located on the curbside of the arterial street, although less case examples exist for this configuration. Unless right turns are restricted, merging and conflicting movements impair the safety and efficiency of curbside concurrent flow HOV lanes. In cases where turning restrictions may meet with widespread opposition, there are two different concurrent flow HOV curb lane alternatives with permitted right turns. The first alternative is a continuous curb HOV lane that allows merging of right-turning traffic into the HOV lane at an appropriate distance upstream of the intersection (Figure 6). The second treatment is a right-turn only lane except HOVs, or essentially a shared turning lane that permits HOVs (Figure 7). Occupancy violations in curb HOV lanes are difficult to enforce, as the accused always declares his innocence as a right-turning vehicle. The proper design and operation of bus pullouts at locations of local bus service is essential for smooth, continuous operation of a concurrent flow curb HOV lane (Figure 8).

Contraflow

A contraflow HOV facility operates one or more lanes in a direction of travel opposite to the adjacent mixed-flow traffic (Figure 1). Contraflow HOV lanes may utilize an additional lane, or "borrow" a lane from the off-peak direction mixed-flow traffic. The contraflow lanes are usually separated from the general-purpose lanes with plastic posts or pylons, and more recently, movable concrete barriers (18). Because a lane is typically "borrowed" from the off-peak direction for contraflow HOV lanes, the off-peak direction

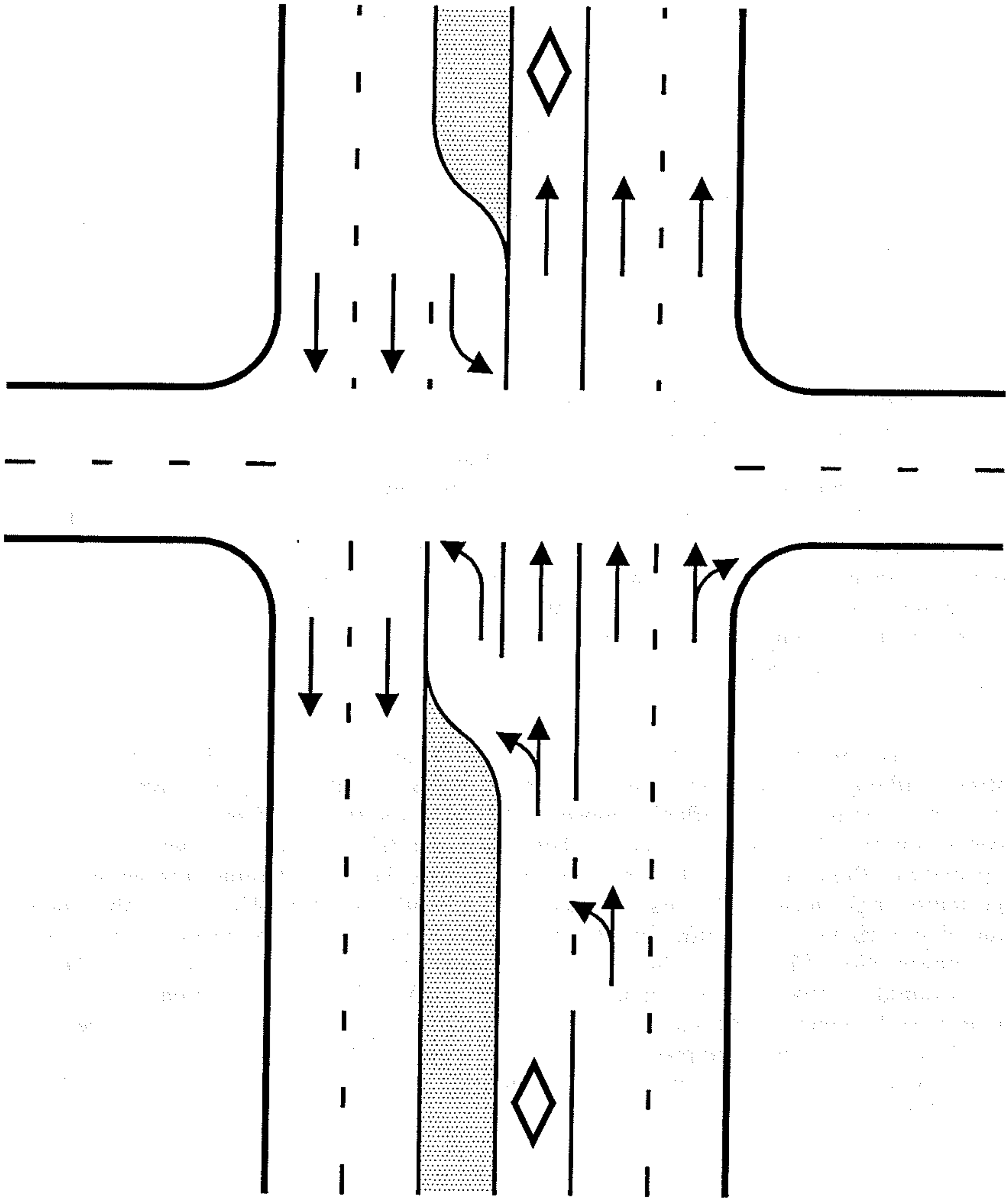


FIGURE 4. Continuous left-side lane with a left-turn bay

Source: Parsons Brinckerhoff Quade & Douglas, Inc., 1992.

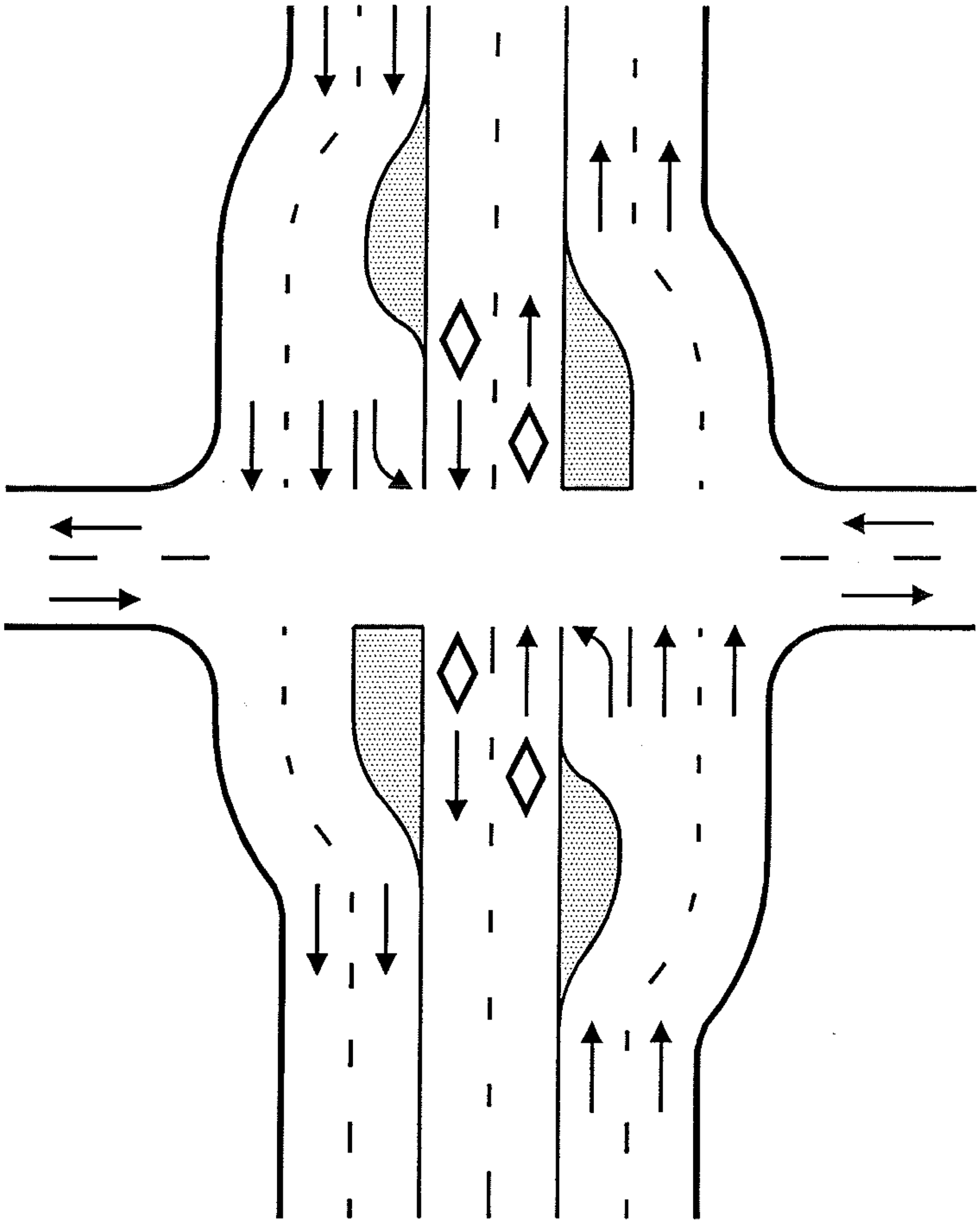


FIGURE 5. Continuous left-side lane with special left-turn phasing

Source: Parsons Brinckerhoff Quade & Douglas, Inc., 1992.

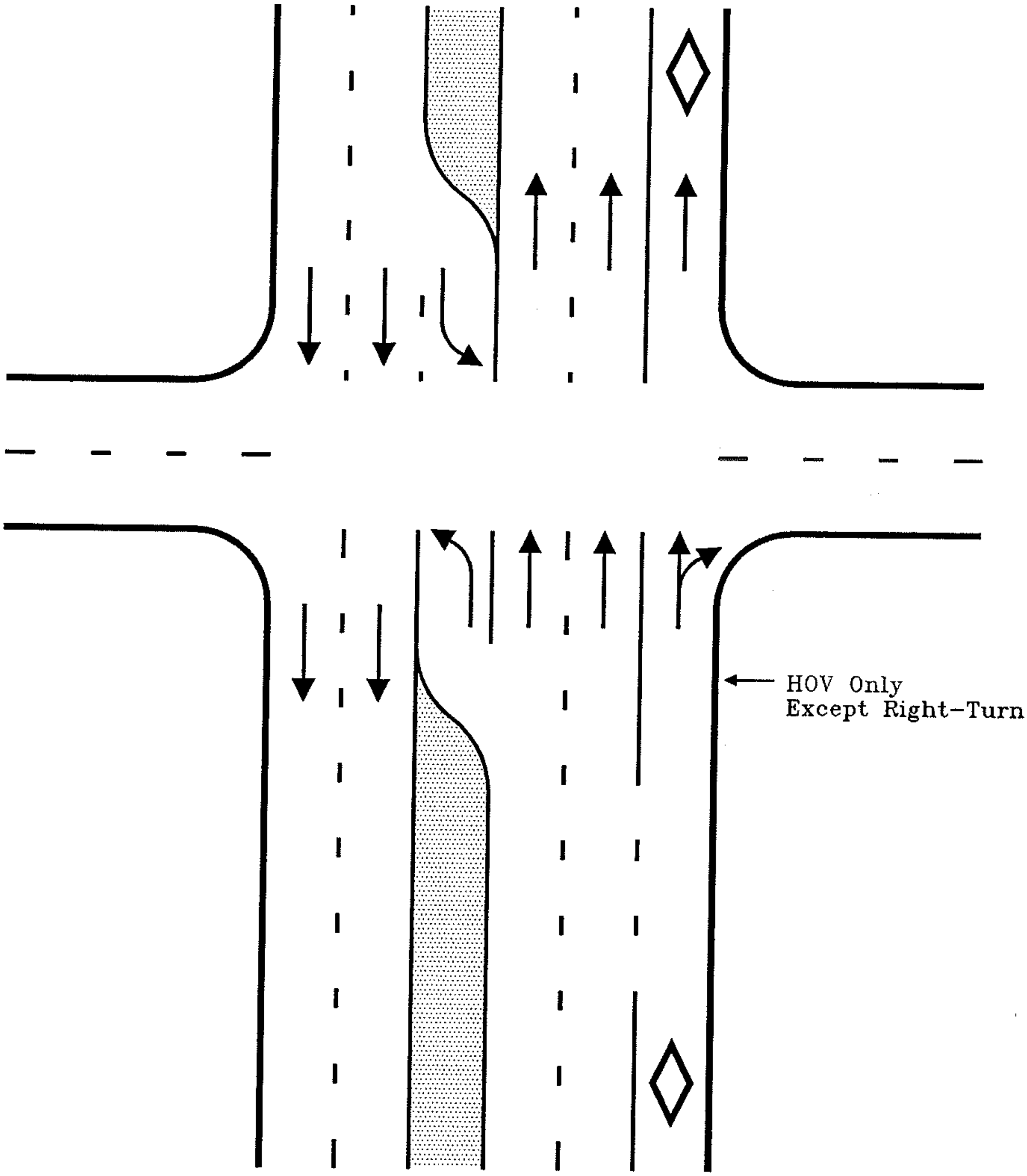


FIGURE 6. Continuous right-side lane with permitted right turns

Source: Parsons Brinckerhoff Quade & Douglas, Inc., 1992.

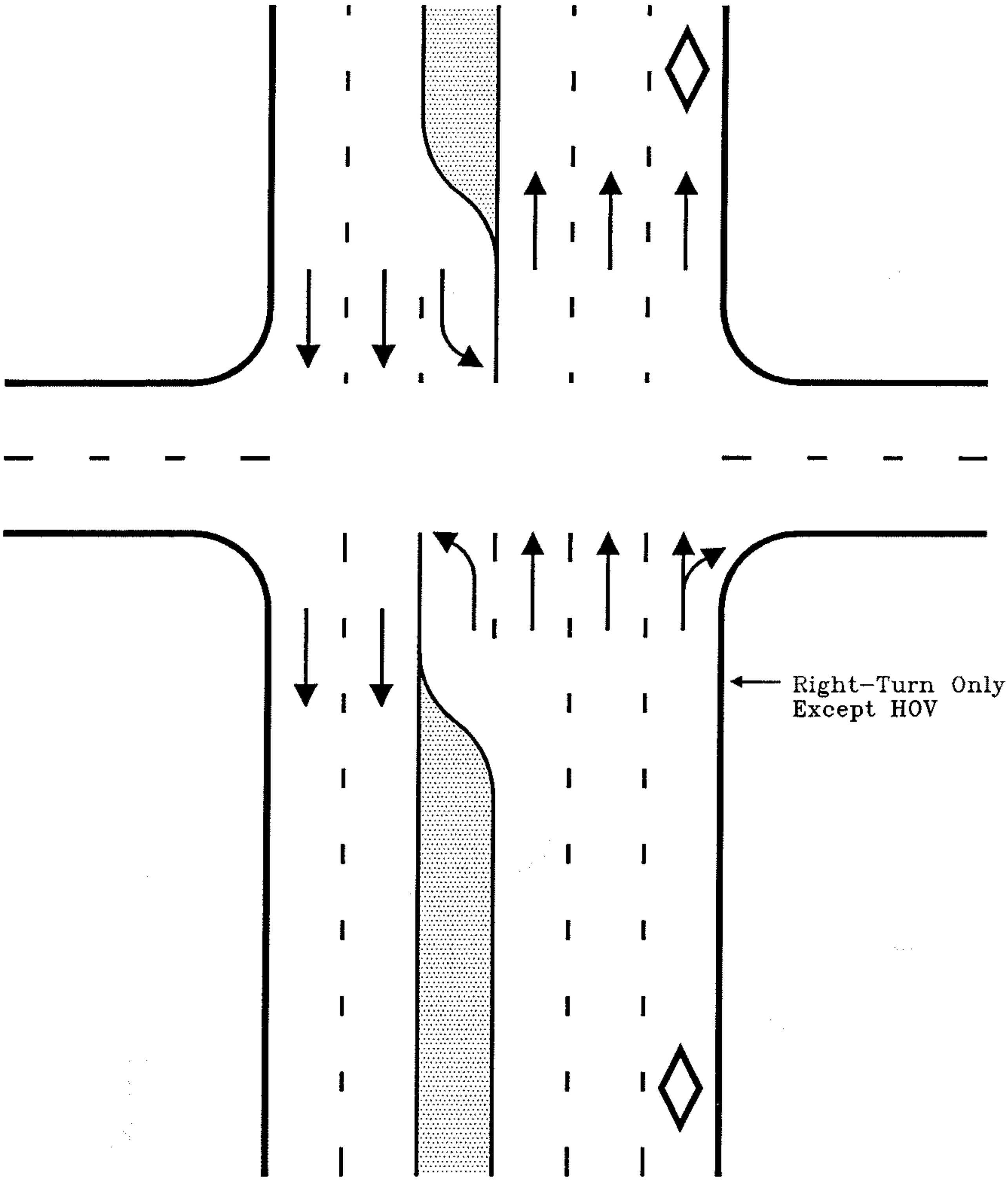


FIGURE 7. Continuous right turn lane with permitted HOV use

Source: Parsons Brinckerhoff Quade & Douglas, Inc., 1992.

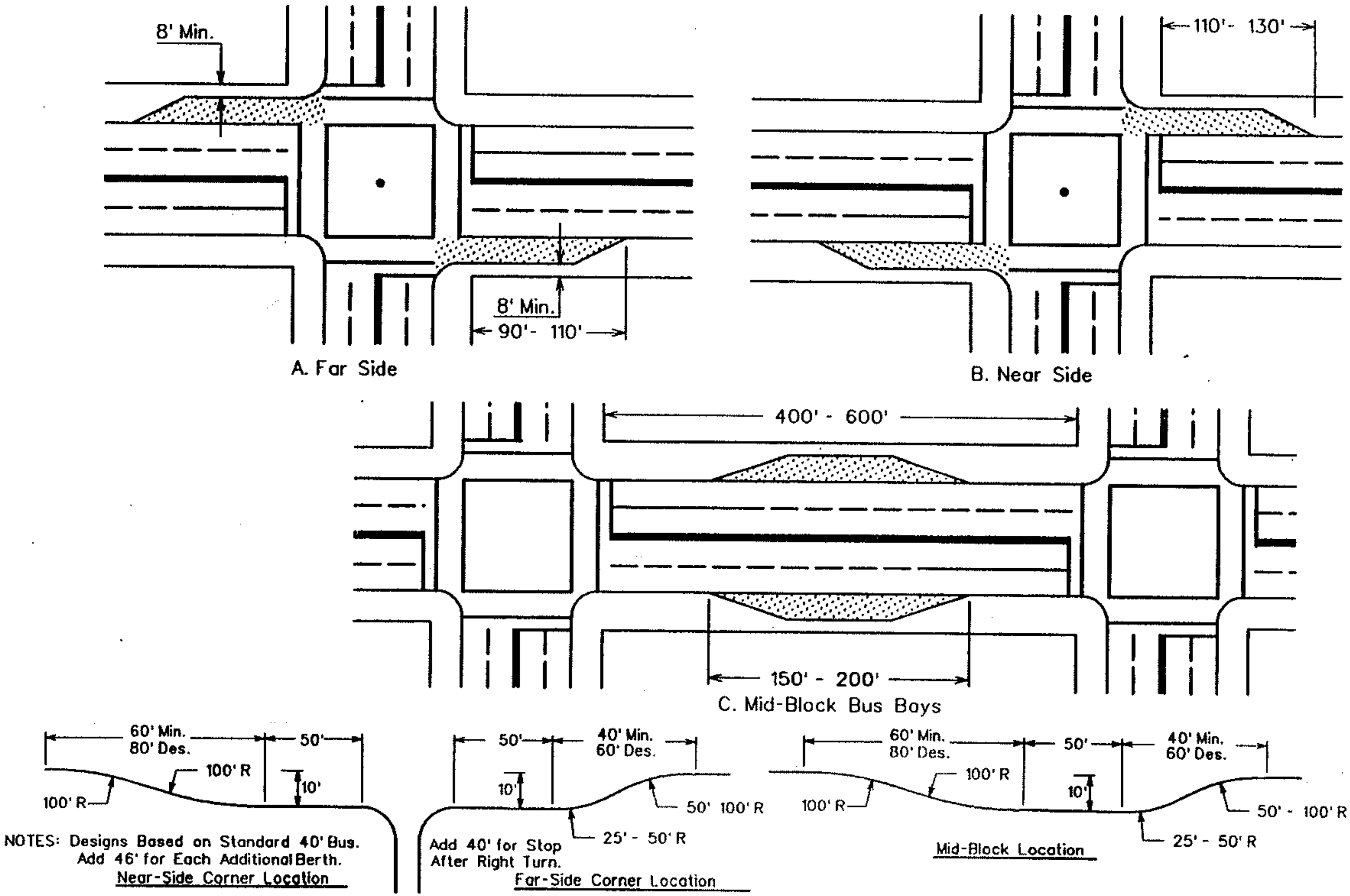


Figure 8. Bus Stop Turnouts and Arterial Streets.

traffic should not be significantly affected by the capacity loss of one lane. Safety is perhaps the largest concern with the use of contraflow HOV lanes. Violation is typically not a large concern because of the relative ease of enforcement.

The Kalanianaole Highway, a four-lane undivided arterial serving downtown Honolulu, uses a 3.1-kilometer (1.9-mile) segment of contraflow HOV lane during the morning peak period (16). A bus-only lane was initiated in 1973 for express bus service to the Honolulu CBD, but the lane was opened to carpools with three or more occupants in 1975. The contraflow lane is delineated by plastic cones and portable traffic signs. The initial travel time savings was estimated at approximately 3 minutes, and the project was judged a success by the public.

Perhaps the longest contraflow HOV facilities on an arterial street are the bus lanes on two parallel arterial streets, Ponce de Leon and Fernandez, in San Juan, Puerto Rico (5). The two one-way arterial streets both have three lanes for mixed-flow traffic and a reserved contraflow lane for HOVs. The bus lanes, approximately 17.6 kilometers (10.9 miles) in length, operate 24 hours a day. Violations have been insignificant although enforcement efforts, signing, and marking is negligible. Accidents on the facility were initially high, but later declined to rates below that before the lane was implemented. Travel time savings were immense over the entire length of the project, and have been estimated at over 30 minutes (35 percent time savings).

Although the speed differential between the contraflow HOV traffic and the mixed-flow traffic on arterial streets is much less than that on freeways, some type of physical separation is almost always warranted for contraflow HOV lanes. Because permanent or movable barriers are typically not feasible in an arterial street environment, separation treatments of plastic cones or pylons have been used with some success despite high operation costs. Raised islands with either barrier or mountable curbs and painted areas have also been suggested as separation elements for dedicated contraflow HOV lanes on arterial streets (12).

Queue Bypass

A HOV queue bypass facility uses concurrent flow, short-distance lanes to detour HOV traffic around isolated capacity restrictions or bottleneck locations. Queue bypass lanes on an arterial street would operate adjacent to the mixed-flow traffic. HOV queue bypasses are much more common in the freeway environment at locations like metered entrance ramps, toll plazas, and bridge and tunnel approaches. HOV queue bypass lanes commonly provide a travel time savings between one and three minutes (2).

The most obvious use of HOV queue bypass lanes on arterial streets is at signalized intersections, where HOVs are allowed to use right-turn only lanes and are provided a merge lane downstream of the intersection (Figure 9). Another application is dual left-turn lanes with one lane reserved for HOVs (Figure 10). Both of these treatments allow HOVs to bypass the long queues associated with poorly operating signalized intersections.

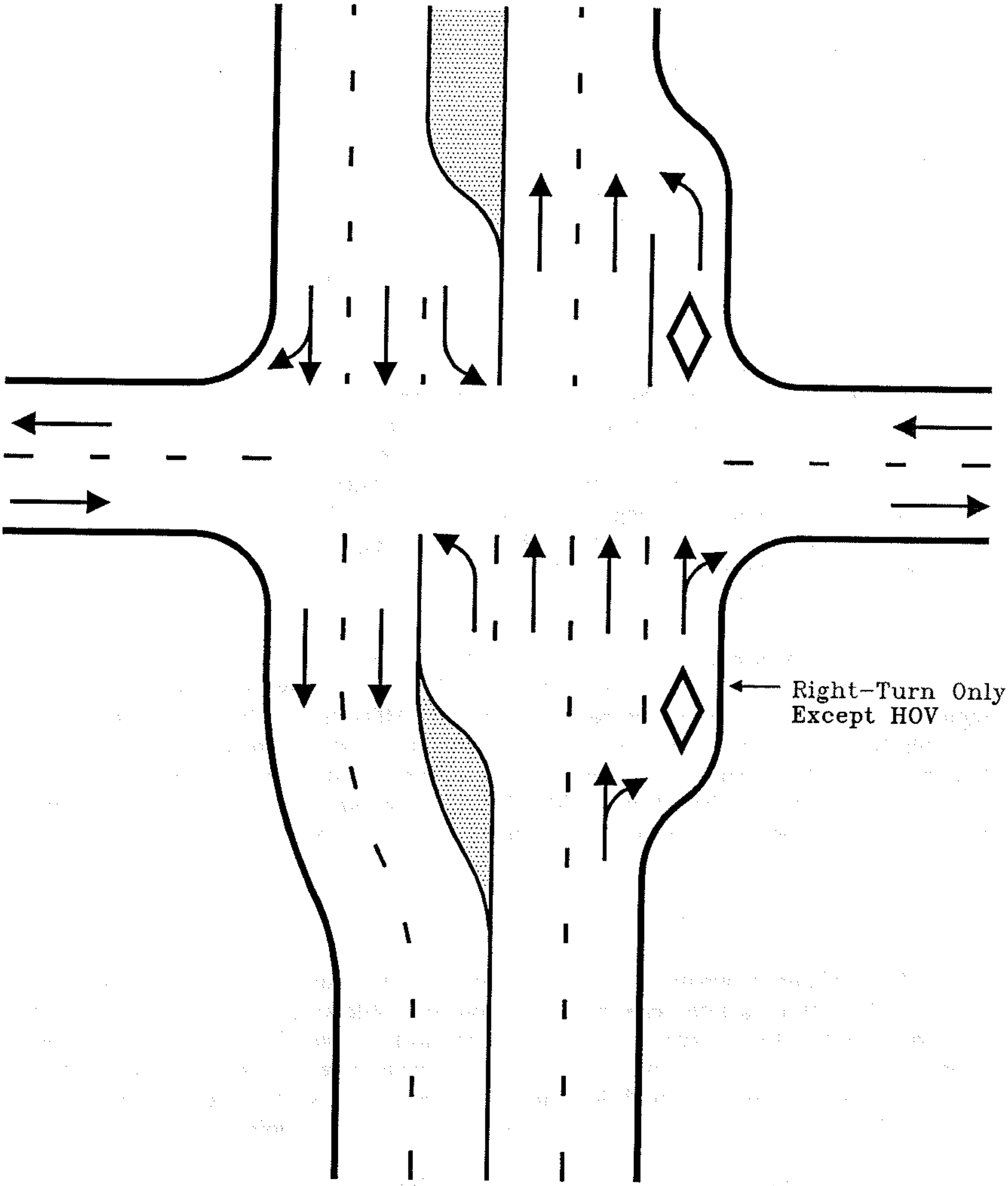


FIGURE 9. Queue bypass lanes with permitted right turns

Source: Parsons Brinckerhoff Quade & Douglas, Inc., 1992.

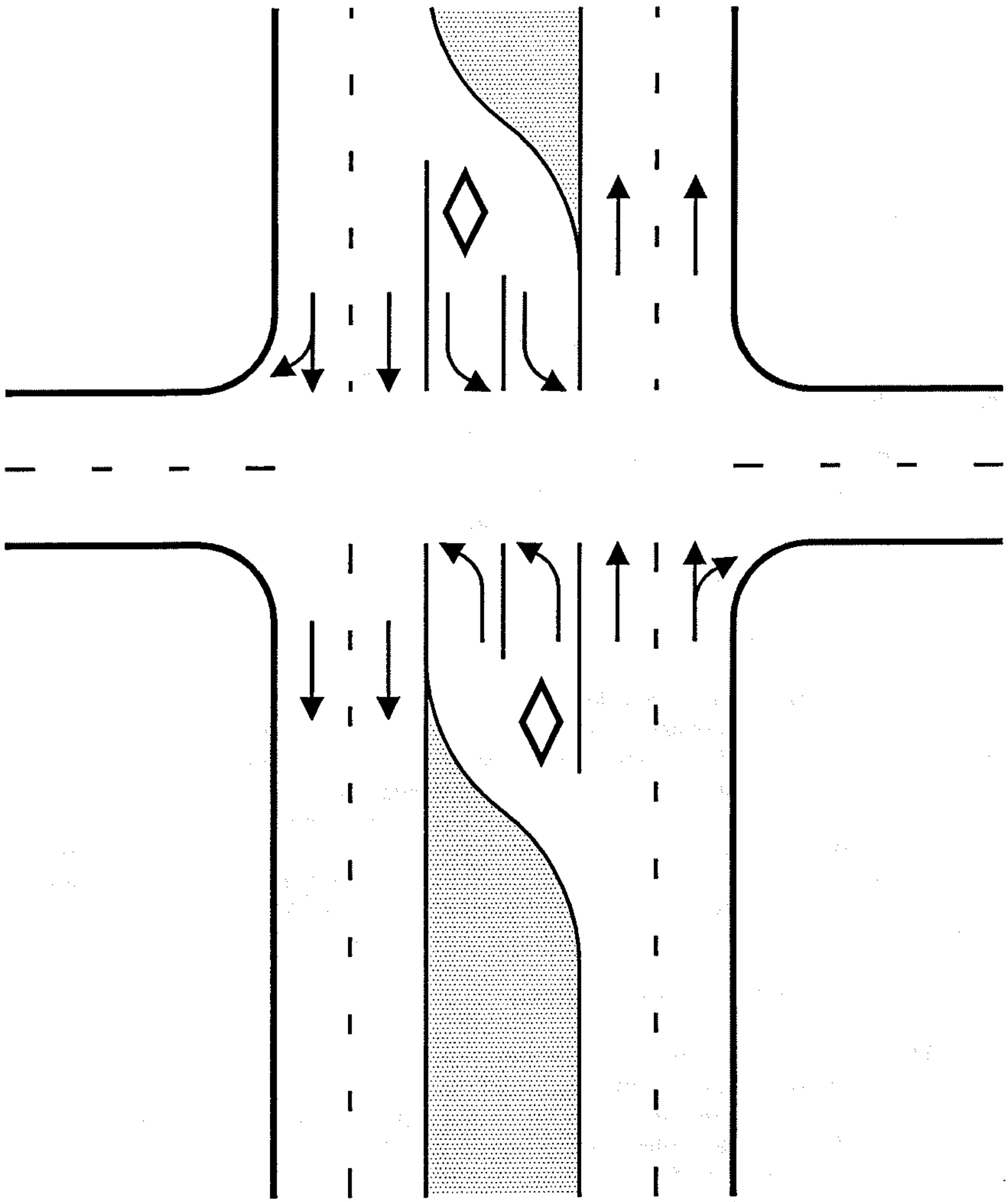


FIGURE 10. Dual left turn lanes with one reserved HOV lane

Source: Parsons Brinckerhoff Quade & Douglas, Inc., 1992.

Signalized Intersection Operation Alternatives

There are several different options that may be used to give priority treatment to HOVs at signalized intersections. The use of turn restrictions with various other arterial operation alternatives has already been presented, but will be briefly discussed below for completeness. Two general types of signal control strategies - preemption and passive priority - will be addressed in. These alternative signal control strategies have been noted as a key component of any arterial street HOV system.

Turn Restrictions

Turn restrictions are commonly placed on single-occupant vehicles in the mixed-flow traffic in combination with other arterial street priority treatments. The restrictions may apply to either right- or left-turns, depending on the type of priority treatment. The chief motivation behind turn restrictions is to eliminate the conflicting movements between turning traffic and HOVs. Although turn restrictions can improve operations of arterial street HOV facilities, they also impede access to cross streets. For this reason, turn restrictions may be met with widespread public opposition along arterial corridors providing considerable access, or those corridors with low percentages of HOV traffic (less than 10 to 15 percent of mixed-flow).

Preemption (Active Priority) Strategies

HOV preemption (active priority) strategies at signalized intersections, usually associated with railroad crossings and emergency vehicles, suspend the normal operation of a signal cycle to give the right-of-way to the preempting HOV. Unconditional preemption occurs at the vehicle's request, while conditional preemption provides flexible control by considering other factors like cross street queues, time since last preemption, and coordination constraints (5). Tags, transponders, or other forms of automatic vehicle identification (AVI) placed on the HOVs may be used to identify the need for preemption, and detector loops and signal controllers provide adaptive traffic control. Preemption strategies for public transit vehicles have met with limited success in the past.

Passive Priority (Specialized Phasing) Strategies

There are several passive priority strategies that may be used for HOVs at signalized intersections. The simplest is adjusting the signal timing to favor HOVs. These adjustments may consist of lengthening the signal cycle, terminating the green phase of the opposing flow early, or extending the green phase in the direction of HOV travel. Another technique, similar to the metering of traffic at freeway entrance ramps or mainlanes, is preferential "gating" or metering. This technique regulates the flow of traffic (with the exception of HOVs) through an intersection or other key access point. Bypass or priority lanes could be provided at the point of metering, or special phasing could be incorporated that was preempted or gave priority to HOVs. Although the adjustment of signal timing is certainly a technique applicable to arterial street HOVs, it is questionable whether preferential "gating" would be acceptable to suburban commuters. Such a restriction on the mixed-flow traffic is likely to anger most motorists operating in already-congested conditions.

Combining Operation Alternatives

The above discussion divided the operation alternatives into two broad categories: arterial treatments and signalized intersection treatments. This is not to imply, however, that these alternatives may only be considered for separate implementation. In fact, the efficient operation of an arterial street HOV facility may rely heavily on the combination and coordination of these operation alternatives. For example, a reversible flow HOV lane must consider either specialized phasing or turn restrictions for proper operation. A concurrent flow HOV lane would probably achieve the most benefits when used with conditional preemption. Priority treatments at the signalized intersection should be consistent and compatible with treatments along the arterial.

Vehicle/User Eligibility

Determination of vehicle/user eligibility for HOV facilities primarily concerns carpools and the associated occupancy restrictions. Historically, carpools and vanpools have not been eligible for HOV priority treatment on arterial streets; however, a suburban environment almost requires the inclusion of carpools because of less intense transit service and a potentially large market for ridesharing. Carpool occupancy restrictions on the few operational arterial street HOV facilities have required two or more (2+) persons per vehicle. In a suburban setting, demand is typically not great with a 3+ occupancy restriction. Because carpool utilization is higher for 2+ occupancy restrictions, the public perception and support of the HOV concept should be more favorable. In the case of 2+ restrictions, additional benefits accrued by two-person carpools increase the cost-effectiveness and efficiency, provided the HOV facility operates below its capacity.

Besides the traditional HOVs like buses, vanpools, and carpools, several other types of vehicles have been permitted to use HOV lanes on freeways. The use of HOV lanes by emergency vehicles contains merit on congested arterial streets. Motorcycles have been allowed to use freeway HOV lanes in a limited number of cases to remove them from potentially unsafe, high-volume traffic. The lower speeds of an arterial street, however, probably would not warrant HOV lane use by motorcycles. Empty transit buses on a return trip, or "deadheading" vehicles, may also be permitted to use HOV facilities. "Deadheading" vehicles are typically handled on a case-by-case basis, where the transit agency is issued a conditional permit. "Deadheading" could be permitted on arterial streets where the HOV facility is not fully utilized to maintain the perception of acceptable usage.

Hours of Operation

An HOV facility may be operated as such on a continual basis (24 hours a day) or only during the morning and evening peak periods. The most practical mode of operation is determined by the traffic distribution and peaking characteristics for the subject corridor. Some HOV operation alternatives, like exclusive or reversible lanes, require continuous operation. If continuously-operating HOV facilities are practically empty during off-peak periods, there may be a perception that the lanes are simply wasted right-of-way that could be used for mixed-flow traffic, even though no congestion may be occurring in the general-purpose lanes. In a suburban setting with typically high peaking characteristics, peak period operation would be warranted more often than continuous operation. Again, a detailed corridor traffic study performed in the initial feasibility stages could be used to ascertain the most suitable hours of operation.

Enforcement

The enforcement of HOV violations is perhaps one of the largest barriers to implementation on arterial streets. Violation enforcement is the principal reason why most previous and existing arterial street HOV facilities operate as bus-only lanes. Many of the operation alternatives discussed earlier offer easy opportunity for violations because of a lack of physical separation.

Besides the almost constant presence of enforcement personnel, there are several techniques using developing technology that may find application in arterial street HOV enforcement programs. The HERO hotline program, instituted on Seattle area freeways, allows motorists to report the license plate number of HOV violators, who consequently receive HOV educational material, warnings, and possibly fines in the mail (19). The HERO program has been touted as a large success with a 33 percent reduction of violation rates, and is certainly applicable to arterial streets. The use of surveillance cameras that record the license plate number of violators may offer a similar promise for such "ticket-in-the-mail" programs. Currently in the developmental stages, an image recognition system could detect the occupancies and license plate numbers of all vehicles in the HOV lane. Such a system would significantly reduce enforcement personnel and HOV violations.

An effective enforcement program for arterial streets must also consider the potential of the HOV facility being located in several different jurisdictions. A concept used successfully on freeway HOV facilities is the project management team. This team would consist of all agencies and jurisdictions involved with operation, maintenance, and enforcement of the facility. A lead agency could then help to coordinate the multi-agency or multi-jurisdictional effort, and identify and assign specific responsibilities to individual agencies.

Support Facilities and Programs

Support facilities and programs also play an important role in the success or failure of arterial street HOV facilities. Parking facilities, like park-and-ride or park-and-pool lots, located near a concentration of trip origins, can attract suburban commuters and provide an essential basis for minimum flows required on arterial street HOV lanes. Preferential parking and other priority parking measures provided by suburban employers are often used as incentives for carpooling. Because employee parking is often subsidized in suburban office centers, the development of parking demand management programs by suburban employers can generate employee interest in ridesharing. Employers are also integral in public education and support programs. Commuter matching services and HOV promotion could be sponsored by the employer, as well as offering flexible work hours to HOV commuters.

FINDINGS

This report has attempted to address the major planning and operation issues of HOV priority treatments on suburban arterial streets. Although many HOV facilities have been implemented on arterial streets, most operations have been restricted to buses only and are located in areas of dense transit service like the CBD. The literature review conducted for this study indicated that, although sufficient documentation existed for freeway HOV facilities, very few guidelines existed for the implementation of arterial street HOV facilities. This section contains a summary of the major findings of this study in regard to the major planning and operation issues.

Planning Issues

As highway right-of-way and financial resources become less available, a greater emphasis has been placed on the overall merits and worth of proper transportation planning. Increasing the efficiency and economy of the existing transportation infrastructure has been placed paramount on the agenda of most transportation professionals and policy-makers. Person-carrying capacity is now stressed as opposed to vehicle capacity; the prerequisite for most government funding is a properly documented plan.

Integration of Freeway and Arterial Street HOV System

Many metropolitan areas in the United States have already or are in the process of adopting an HOV system plan that includes HOV facilities on freeways only. Arterial streets have not been included in these plans because of a lack of recent operating experience or documentation of effectiveness. Arterial street HOV facilities, when integrated with a freeway HOV system, can play an important role in providing priority treatment for the trip distribution functions. The connection of arterial street and freeway HOV facilities allows HOVs to maintain or extend their travel time savings over a significant portion of their trip.

Important Elements in Assessment of Conceptual Viability

Enforcement, safety, minimum utilization, and agency and public support are perhaps the four most crucial elements necessary for the success of any arterial street HOV priority treatment. Initial planning efforts should concentrate on developing an HOV program that addresses these concerns. Developing technologies and innovative self-enforcement programs (like the HERO hotline) for HOV enforcement offer promise on arterial streets. Increasing familiarity with the HOV concept and associated lane configurations, in addition to a uniform marking and signing policy, can provide for the safe and efficient operation of HOV facilities on arterial streets. Little documentation was found on the estimation of HOV demand for suburban arterial streets.

Operation Issues

Many of the perceived barriers to implementation of arterial street HOV facilities concern operation alternatives and their respective feasibilities in a suburban arterial street environment. There are several operation alternatives for arterial and signalized intersection priority treatments. While some alternatives are more viable than others, there are some alternatives that clearly do not warrant consideration on suburban arterial streets.

Arterial Operation Alternatives

Exclusive facilities, like bus streets, bus tunnels, or transit malls, have little application in a suburban setting, where development and transit service typically are not dense enough to justify an exclusive treatment.

Reversible flow facilities may be considered along a densely traveled radial corridor where the directional distribution is greater than 65/35 percent during the peak periods. This treatment is best located in an arterial median with some type of physical separation, although barrier-separation is not recommended on arterial streets. Provisions should also be made for an some type of transit station, as loading and unloading of bus patrons in the median is a potential safety hazard.

Concurrent flow HOV facilities are perhaps the most feasible operational treatment on suburban arterial streets. Typically nonseparated from the general-purpose lanes, concurrent flow lanes are currently operating on several arterial street HOV projects. Location of the priority lane on the inside or left-side of the general-purpose lanes is the more effective treatment, and when used with left-turn restrictions can provide efficient operation. A curb HOV lane presents a significant enforcement problem, as well as conflicting movements with right-turning traffic and driveway ingress and egress.

Contraflow facilities have inherent safety problems because of the close proximity of opposing traffic flows. If contraflow facilities are a possibility on arterial streets, a physical separation should be provided. Temporary plastic posts or cones have been used, and the painted or raised islands have also been suggested. Barriers, permanent or movable, are not feasible or cost-effective in an arterial street environment.

Queue bypass lanes are certainly applicable to arterial street HOV facilities at the principal source of congestion, signalized intersections. Although they may provide less of a travel time savings than longer priority lanes, the use of queue bypass lanes at several consecutive intersections could provide an incentive for HOVs. When integrated with alternative signal control strategies, this treatment could have significant time benefits.

Signalized Intersection Operation Alternatives

Priority treatment at signalized intersections could warrant the most attention in development of an arterial street HOV facility. The use of turn restrictions in conjunction with other arterial operation alternatives can enhance the operation of arterial street HOV facilities. There are some locations or corridors where turn restrictions would not be politically or publicly popular, and these should be identified through public input at hearings and outreach programs.

Preemption strategies can provide significant benefits to HOVs, but only at the expense of mixed-flow traffic. Because HOV traffic typically constitutes only 20 percent of the total traffic, preemption strategies would be difficult to implement without widespread political and public opposition. Passive priority strategies, however, use adaptive traffic control to provide HOVs with priority treatment. Developing technologies in signal controllers and detection systems offer significant promise for arterial street HOV facilities. Also, the coordination and integration of operation alternatives for line-haul treatment and intersection priority.

Hours of Operation

The hours of operation should be determined through a corridor traffic study of the distribution and peaking characteristics. In a suburban setting where peaking is high during the peak period, peak period operation would be the most feasible and publicly acceptable alternative.

Enforcement

Enforcement plays a key role in the continued operation and success of arterial street HOV facilities. As mentioned earlier, developing technologies and innovative self-enforcement programs (like the HERO hotline) for HOV enforcement offer promise on arterial streets. Some operation alternatives are also easier to enforce than others. Unfortunately, one of the most feasible operation alternatives, concurrent flow, is also one of the most difficult to enforce.

Support Facilities and Programs

The involvement of suburban employers in HOV support programs is another aspect that should be considered in implementation and operation of arterial street HOV facilities. Commuter matching services, flexible work hours, preferential parking, and HOV education programs could be provided by employers, and would form a basis for utilization of area HOV facilities. Consideration should also be given to the various support facilities necessary to encourage ridesharing and public transit modes, like park-and-ride and park-and-pool lots, transit stations, and areawide activity center parking demand management.

RECOMMENDATIONS

Planning and Operation of Arterial Street HOV Facilities

The major issues regarding planning and operation of priority treatments on suburban arterial streets have been discussed in this report. It was found that the freeway HOV experience was not directly transferrable to the arterial street environment. Because of the importance of a regionwide HOV system, an attempt should be made to integrate freeway and arterial street HOV facilities. Candidate HOV corridors should consider the various arterial and signalized intersection operation alternatives, and the applicable combinations, discussed in this report. Because arterial street corridors have such a wide variance in site conditions, an HOV alternatives analysis should carefully consider the area location, arterial geometry, HOV and mixed-flow traffic volumes and distributions, projected public and political acceptance, and other factors that affect the success of the HOV project implementation.

The operation of arterial street HOV facilities should be based on current HOV experience on arterials as discussed in this report, systematic evaluations of newly-implemented facilities, and lessons learned from the freeway HOV experience. Until more documentation becomes available regarding the operation of arterial street HOV facilities, operational issues will need to be resolved using these tools as they had been used in the early 1970s with the beginning of the implementation of freeway HOV facilities.

Further Research

Recent research, funding, and application of HOV priority treatments has been concentrated on freeway facilities. Research has been funded by the Urban Mass Transportation Administration (UMTA), now the Federal Transit Administration, to investigate the history, institutional arrangements, operating experience, and effectiveness of freeway HOV facilities. The literature search and review conducted for this study found a lack of documentation of HOV facilities on arterial streets. Although operation and design guidelines and criteria do exist for bus facilities in downtown or CBD areas, few comprehensive references were found that related to all traditional HOVs in a suburban arterial setting.

It is the recommendation of this study that research be conducted to document the operating experience of existing arterial street HOV facilities and address the effectiveness of the facilities. The research, like that conducted for freeway HOV facilities, would do the following three things: 1) use a survey to identify current arterial street HOV projects and their characteristics, 2) assess the individual projects with the use of representative case studies, intended to identify design and operation guidelines for future arterial street HOV projects, 3) develop a methodology for assessing the effectiveness of arterial street HOV projects.

The results of this research would complement the excellent documentation of freeway HOV facilities, and assist in the development of regional HOV system plans that incorporate both freeways and arterial streets.

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