Alternatives for Providing Priority to High-Occupancy Vehicles in the Suburban Arterial Environment

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During the past 20 years, restricted lanes for high-occupancy vehicles (HOVs) have become a familiar feature of the freeway environment in many areas of the country. HOV lanes allow buses and carpools to bypass delay during congested peak periods, increasing the attractiveness of alternatives to travel by single-occupant vehicle. As continued suburban growth in major metropolitan areas limits mobility on arterial roadways, the need for a similar solution for suburban arterials is becoming increasingly apparent, but HOV facilities remain rare in the suburban arterial environment. Suburban arterials are complex in their function and design, making the simple application of the basic freeway HOV lane concept difficult. The alternatives for providing HOV priority in the arterial environment studied in Snohomish County, Washington, a suburban county in the Seattle metropolitan area, are discussed. All of the treatment options that have been used to provide priority to HOVs were considered. The advantages and disadvantages of treatments that show some potential for success are discussed. An important finding is that suburban arterial HOV treatments must be focused on reducing delay for HOVs at signalized intersections since congestion emanates from the signalized intersection in this environment.

Community Transit completed its Arterial System HOV Study in March 1993. The study examines the potential for high-occupancy vehicle (HOV) facilities, which allow buses, vanpools, and carpools to bypass congestion, to provide options for travel mobility in the suburban arterial environment of Snohomish County, Washington. The focus of this paper is on the first phase of the study, which involved the identification of a comprehensive set of alternatives for HOV priority. This identification of alternatives was followed by the development of an analysis methodology and the analysis of 100 mi of suburban arterial segments in key travel corridors. In the alternatives identification stage, the advantages and disadvantages of the alternatives were discussed in relation to the general characteristics of the Snohomish County arterial environment. "Alternatives" was broadly defined and included physical treatments and distinct options for their implementation and operation.

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KEY DISTINCTIONS BETWEEN THE ARTERIAL AND FREEWAY ENVIRONMENTS

The objective of arterial HOV treatments is essentially the same as that of freeway HOV treatments: to bypass congestion. Bypassing congestion provides a travel time advantage to HOVs, which is the key to achieving several basic goals commonly associated with HOV treatments, such as increasing transit ridership, increasing the efficiency and passenger-carrying capacity of a facility, and maintaining mobility in the face of severe congestion. There are, however, some clear distinctions between HOV considerations for the suburban arterial environment and those for the freeway environment. These distinctions include the sources of suburban arterial congestion, the geometric and operational characteristics of the arterial, and the function of arterial roadways.

On the suburban arterial, congestion emanates primarily from the signalized intersection, where queues develop and system delays occur. A primary focus in the development of alternatives for HOV priority treatments in an arterial environment must be the signalized intersection because bypassing congestion is the primary objective of HOV treatments.

The geometric and operational characteristics of arterial roadways are quite different from freeways: lane widths may be narrower, speed limits are lower, access restrictions are fewer, and the roadways are signalized to accommodate at-grade intersections. Arterial roadways are also complicated by the variety of activities they serve. Motor vehicle traffic on arterials must interact safely with bicycle and pedestrian movements. Through traffic on arterials competes for roadway space with traffic that is turning to the right or the left or entering the roadway from side streets or driveways. HOVs taking advantage of priority treatments face turning conflicts that may cause safety and operational problems. Bus stops and bus reentry into the traffic flow may cause additional conflicts. Enforcement activities are hampered by the complex movements of the arterial environment and the limited space available for enforcement vehicles. All these differences limit the applicability of HOV experience developed in the freeway environment.

Arterials also serve a different function than that of freeways: they generally provide access within local areas instead of linking more distant areas. Although trip distances on arterials tend to increase as freeways become increasingly congested, arterials continue to serve their local access function, even as they become long-haul alternatives. Therefore the different functions of the arterial roadway in the transportation system must also be recognized in the development of HOV treatments for the arterial environment.

VIABLE ALTERNATIVES

Some alternatives were found to have no potential to meet several basic criteria for effectiveness and were eliminated from further analysis. These macro-level screening criteria were financial viability, geometric feasibility, functional adequacy, and public acceptability. In this section, the alternatives that passed the fatal flaw screening are identified and described. Past experiences with these alternatives are noted, and advantages and disadvantages are discussed. Some general findings from the corridor-specific analysis of alternatives are discussed. Among the alternatives discussed are signal priority treatments, continuous lane treatments, design alternatives for priority at signalized intersections, and support measures and facilities.

Signal Priority Treatments

A major focus of the study was the analysis of the potential benefits of providing priority to buses or other HOVs at signalized intersections by altering the timing of traffic signals to favor such vehicles. The traffic control philosophy guiding signal priority treatments is that traffic signals should be operated to minimize total person delay. This is a natural evolution from current signal control strategies, which strive to minimize total vehicle delay.

Preferential treatment of an HOV at a traffic signal requires two functions: the identification of the vehicle, involving an automatic vehicle identification (AVI) technology; and the modification of the signal timing in response to that vehicle, an alternative signal control strategy (see Figure 1).

A variety of AVI technologies and alternative signal control strategies was analyzed in the study. AVI technologies include radio frequency transmission, microwave transmission, optical or infrared identification, and surface acoustical wave technology. The advantages and disadvantages of each of these technologies are presented in Table 1. Alternative signal control strategies include traditional preemption, traditional priority, specialized phasing, noncycle-based signal control systems (e.g., OPAC-RT with HOV Preemption), and noncycle-based systems with person optimization instead of vehicle optimization (e.g., HOV-Weighted OPAC-RT). The advantages and disadvantages of these signal control alternatives are presented in Table 2. A traditional priority strategy, simulated using TRAF-NETSIM, was shown to provide total delay savings of about one-third and to eliminate three of four stops at signals by buses.

Continuous Right-Side HOV Lanes

Continuous right-side HOV lanes reserve the outside lane for bus or bus and carpool use along a continuous section of an arterial. A slight variation on continuous right-side HOV lanes is the designation of the right lane as a "local access only" and "right-turn-only" lane for all vehicles except HOVs. All general-purpose vehicles in the lane would be required to turn right at a driveway or at the next available intersection. This

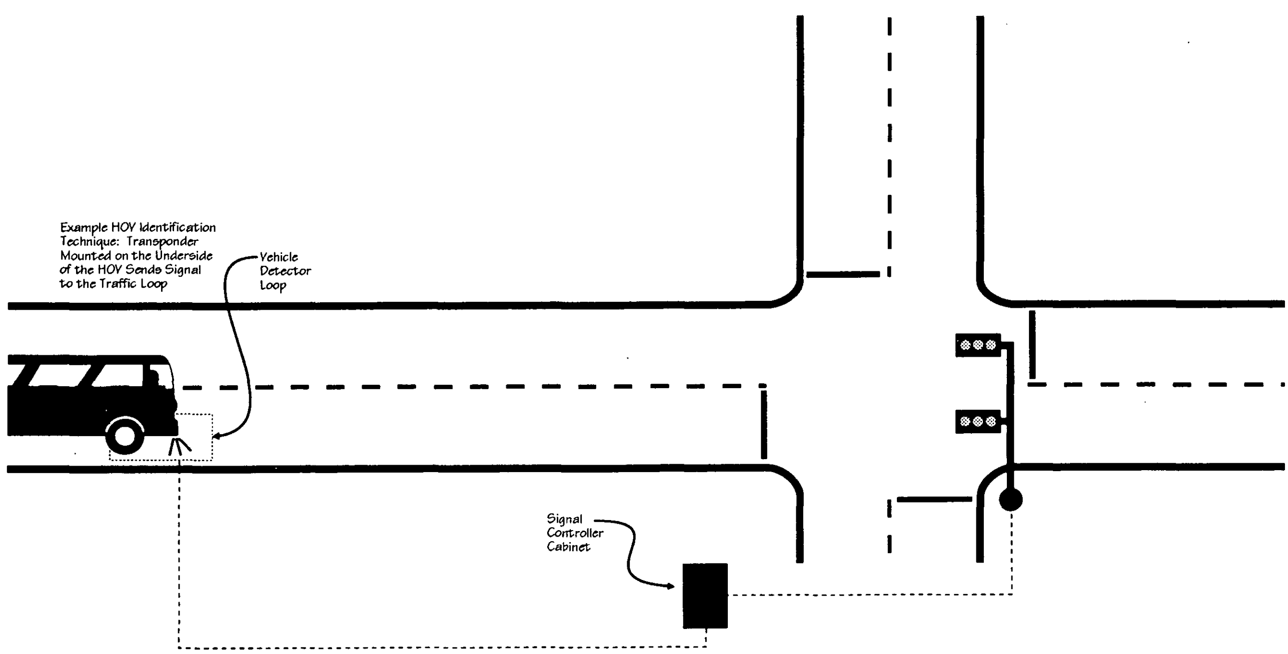

FIGURE 1 Signal priority alternatives.

TABLE 1 Automatic Vehicle Identification Systems

Technology	Configuration	Functions Available	Compatibility with Carpools	Advantages	Disadvantages
Radio Frequency Transmission (RF)	Tags and readers or other roadside or in-pavement antenna; compatible with loop detectors.	ID only; two way communication; voice; transmission of information	Compatible with the use of tags	The most applicable equipment available; compatible with simple tags and more sophisticated systems; used for two-way communication; compatible with roadside or in-pavement antenna.	The amount of data which can be transmitted with a loop configuration is limited.
Microwave	Tags and roadside readers; requires line-of-sight	Same as Radio Frequency Transmission	Compatible with the use of tags	Compatible with tags and two-way communication; transmission is at higher rates than RF.	Line-of-sight transmission, therefore signal can be screened by intervening vehicle; required power levels are high.
Optical/Infrared	Tags or bar-code tags; roadside readers; requires line-of-sight and good visibility.	ID only.	Compatible with the use of tags and bar codes	Compatible with tags/strict mounting requirements for tags and reader; can use bar codes.	Same as for microwave; requires good visibility; susceptible to dirt.
Surface Acoustical Waves (SAW)	Tags and roadside readers.	ID only.	Compatible with the use of tags	Same as for Optical except for use of bar codes.	Insufficient accuracy.

treatment may have essentially the same benefits as a continuous right-side HOV lane and also enhance access to local business. A possible striping and signing concept for this treatment is shown in Figure 2.

Past Experience

Right-side HOV lanes operate successfully in several areas of the country. Examples include the San Tomas and Montague Expressways in San Jose, California, and North Washington Street in Alexandria, Virginia. The San Tomas Expressway HOV lane is an 8-mi facility that operates during the morning and peak periods and is designated for use by buses and carpools of two or more people. The facility was opened in 1982. The Montague Expressway, a 7-mi facility with the same occupancy designation and hours of operation, opened in 1985. The North Washington Street HOV lane, which opened in 1984, is a 3-mi facility that operates during peak periods and is designated for use by buses and carpools of three or more people.

More common than right-side HOV lanes on suburban arterials are right-side bus-only lanes, which have been used for years in downtown areas. At least 95 such projects have been

TABLE 2 Alternative Signal Control Strategies

Strategy	Configuration	Function	AVI Technology	Advantages	Disadvantages
Traditional Premption	Local preemptor connected to controller; may be under system control.	Strict preemption.	Opticom; tag with roadside reader; loop detector with transponder on underside of vehicle.	Simple configuration; inexpensive.	No flexibility of control; possible safety problems with short intervals; disruption of general purpose traffic can be severe; legislative prohibition.
Traditional Priority	Requires traffic control system modification.	Flexible priority treatment.	All of the above.	Very flexible control options; simple concept.	Requires customized equipment.
Specialized Phasing	HOV lane at signal.	Provides priority to HOV lane.	Standard loop detection.	High service level to HOVs.	Directly impacts general traffic movements; requires HOV lane.
OPAC-RT with HOV Preemption	OPAC coordinator unit on standard controller with advanced detection (25 seconds) implements OPAC.	Strict preemption with facilitated recovery.	Same as traditional preemption.	OPAC provides control efficiency to minimize negative preemption impacts.	New technology; disadvantages of preemption.
HOV-Weighted OPAC-RT	Same as above.	Minimizes person delay and stops/maximizes throughput.	Same as traditional preemption.	Maximizes people movement efficiency.	New technology; disadvantages of preemption.

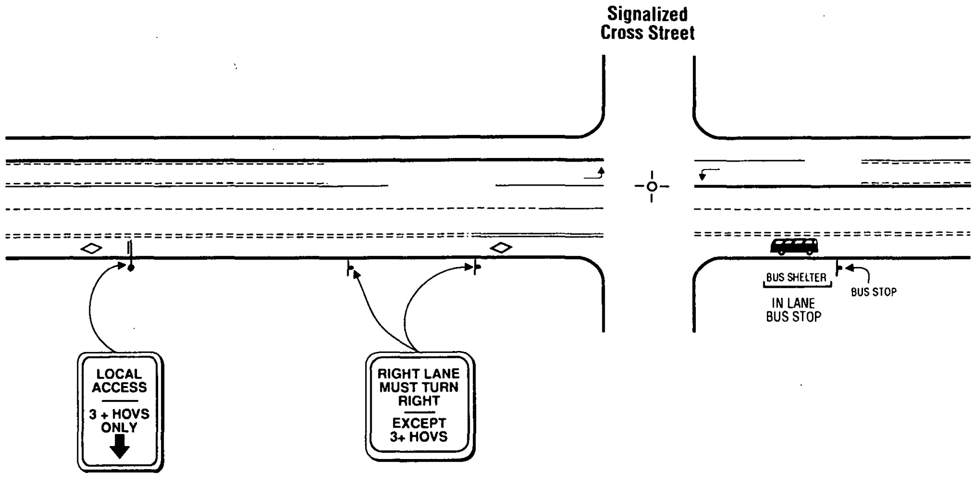

FIGURE 2 Typical striping and signing concept for 3+ HOV emphasis lane.

implemented since 1956, with varying degrees of success. Case-specific factors have produced widely varying impacts on person throughput, transit use, service reliability, and safety. A significant number of these lanes have been suspended because of low use, safety concerns, or enforcement problems, but the majority continue to operate, and data available for many of the operational lanes indicate that they are successful.

In the Puget Sound region, two arterial roadways currently contain right-side HOV lanes. A continuous right-side HOV lane on SR 99 northbound begins at NE 115th Street and ends 1.5 mi to the north at NE 145th Street. The SR 99 HOV lane has a 3+ HOV designation and operates with restrictions 24 hr/day.

On SR 522, a 3.3-mi southbound bus-only lane and a 0.9-mi northbound bus-only lane operate during the (directional) peak hours. During the off-peak periods, the lane reverts to shoulder use in each case.

Advantages

This treatment may be implemented at low cost when parking lanes or shoulders are available for conversion. Right-side HOV lanes provide good access to bus stops. In some cases, it may be the only geometrically feasible option for a continuous HOV treatment.

Disadvantages

Depending on their destinations, some potential users of right-side HOV lanes may need to make a left turn as they leave the HOV corridor. A right-side HOV lane requires them to weave into slower moving traffic to reach a lane from which they can turn left. This weaving movement may cause safety problems, reduce speeds, and reduce the perceived advantage of the HOV lane.

A safety review of HOV lanes in the Puget Sound region of Washington revealed the primary operational difficulties of right-side HOV lanes: HOV traffic comes into conflict with right-turn movements, pedestrian crossing movements, and weaving movements of vehicles entering and exiting driveways (Senn 1990, unpublished data).

In-lane bus stops impede HOV travel in right-side HOV lanes, causing safety problems and reducing travel times for carpools and vanpools forced to wait behind stopped buses. Additional right-of-way would be required to resolve this problem by providing bus turnouts.

Past experience with right-side arterial HOV lanes has shown that they are perceived as short-haul facilities, which makes the lanes less attractive to commuters and limits usage.

Continuous Left-Side HOV Lanes

Continuous left-side HOV lanes may be provided in the middle of two-way, multilane arterial streets where sufficient right-of-way exists. Inside or median HOV lanes would typically operate as concurrent flow lanes.

Past Experience

Median-strip reserved bus lanes have most commonly been used in U.S. cities where street cars previously had been operated in the center median. For example, a two-way busway operates in the median of Canal Street in downtown New Orleans, Louisiana.

Advantages

Operating an HOV facility in the center of an arterial eliminates the various traffic conflicts in the curb lanes, such as conflicts with ingress and egress from driveways and right-turn movements. These advantages lead to higher speeds and reduced stops and delays for HOVs. Left-side HOV lanes are also perceived as being safer than right-side lanes. The left-side treatment may also be perceived as a long-haul treatment because of the reduced conflicts with movements required for local access.

Disadvantages

Inside HOV lanes require bus stops in the center of the roadway. This placement of bus stops forces passengers to cross busy streets to board and exit from buses, increasing conflicts between pedestrians and vehicles. Left-turn movements replace right-turn movements as a potential operational problem. This problem requires restriction of left turns in some cases and special signal phasing in others.

Reversible HOV Lanes with Signal Control

Reversible HOV lanes provide a lane for HOV travel in the peak direction of travel, reversing direction of operation as the peak-travel direction reverses, typically from the morning home-to-work direction to the evening work-to-home direction. Among the various design options, control with signals is a low-capital option that may be suitable for the arterial environment. Lane control consists of overhead signals and variable-message signs. Cones or other manually moveable barriers also may be used in conjunction with a reversible HOV lane.

Past Experience

Many examples of reversible arterials exist, including in the cities of Houston, Memphis, St. Louis, and Charlotte. However no known examples of reversible HOV lanes on arterials exist.

Advantages

Reversible lanes are less expensive to construct than two-way treatments and require less right-of-way. They provide added capacity in both directions, allowing use of lanes that might otherwise be underused in the off-peak direction.

Lane control with signals is the reversible treatment that is probably most suited to the geometric context of the suburban arterial. It allows operation in the peak direction without requiring barriers, which restrict mobility and use roadway space. Lane control with signals may be implemented and operated at a lower cost than more capital-intensive reversible lane options.

Disadvantages

Without careful design, traffic control for reversible lanes may be confusing and dangerous because of the possibility of wrong-way movement. The lanes may be perceived as dangerous even if adequate safety measures are provided. To be effective, the treatment requires a strong directional split, which is not common in most arterial settings. Although the treatment is not capital intensive, it may be labor intensive if it requires daily cone movements.

Signal Queue Jump

A spot application of HOV priority treatment involves allowing access to right-turn only drop lanes at traffic signals for through movements by buses, carpools, or both. An additional merge lane downstream of the intersection is provided to allow HOVs using the right-turn drop lane for queue bypass to re-enter the through traffic flow. A special phase for the HOV movement may be provided with this treatment. See Figure 3.

Past Experience

A 1,000-ft curbside HOV lane has been implemented on NE Pacific Street in Seattle's University District, with signal priority at the intersection of NE Pacific Street and Montlake Boulevard. A signal queue jump currently operates at NE 4th Street in downtown Bellevue, Washington.

Advantages

This treatment reduces HOV delays and improves transit reliability. The costs of the treatment are relatively low, requiring widening for a distance downstream of the intersection. A standard for the length of this widening is 12 ft/sec of average green time. The length of widening upstream of the intersection is a function of the maximum normal length of the queue of general-purpose vehicles waiting at the signal.

Disadvantages

Additional merging is required downstream of the intersection, which would increase traffic conflicts and potentially produce a higher accident rate. These impacts could be mitigated by providing an HOV "early release" control strategy at the signal, but the early release would in turn increase delay and reduce capacity for general-purpose traffic. Therefore, such an early release strategy is most appropriate at nonbottleneck intersections. Conditions would have to include relatively minor queuing for peak-hour right turns, significant queuing upstream of the intersection, and freedom from bottlenecks for a considerable distance downstream of the intersection to allow easy re-entry into the through traffic flow. If any of these conditions were to change significantly after implementation of the treatment, many of the benefits of the treatment would be lost. The treatment would be geometrically feasible only where existing right-of-way allows for the downstream merge lane.

Special Access

Special access for HOVs, such as HOV-only freeway ramps or HOV-only connecting streets, provide a time-saving shortcut to HOVs at key points in their travel routes. Such treatments could be used as links to other HOV treatments, such

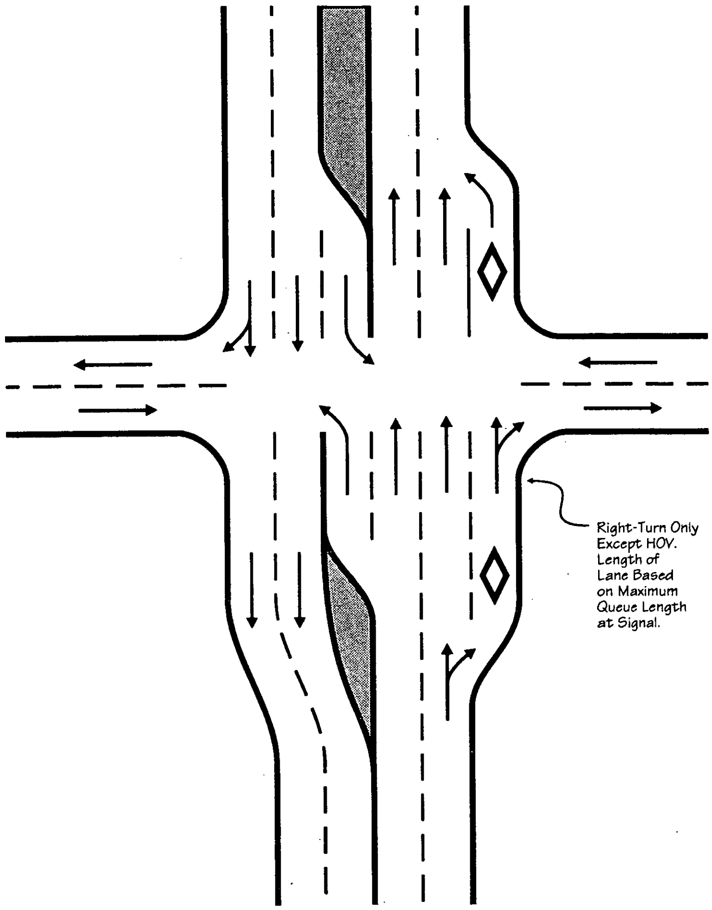

FIGURE 3 Signal queue jump.

as HOV lanes, ramp bypasses, or park-and-ride lots. In some cases they may be effective as stand-alone treatments.

Advantages

Special-access facilities could improve the connectivity of the arterial system to existing HOV facilities and could have a positive impact on mode shift by making HOV modes more desirable at key locations.

Disadvantages

Special-access facilities do not have any general disadvantages. In specific cases the facility that would be required to provide special access may be excessively costly.

CONCLUSION

Of the various arterial HOV alternatives that have been implemented in the United States and abroad, all have advantages and disadvantages that require evaluation of the particular application. The characteristics of the arterial environment are diverse and complex enough to preclude general conclusions regarding any particular alternative. Signal priority treatments that use advanced technologies to minimize person delay at intersections appear to have the most universal potential to achieve the goal of bypassing congestion without unacceptable impacts to general-purpose traffic, but such treatments are nevertheless limited by intersection capacity constraints.

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