TRANSIT IMPLICATIONS OF HOV FACILITY DESIGN

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16. ABSTRACT

While several authorities have assembled comprehensive general resources on the design and operation of HOV facilities at large, none has yet done this from the perspective of transit. The lack of transit-specific research has left unanswered questions such as "What are transit's interests, and how are they best served in HOV facility design and operations?" In addressing these questions, the authors of this report have brought together many pieces of available transit-related HOV research into a single document. The report covers technical aspects of HOV design and operations by dividing the domain into two components: freeways and arterials. Part One, *Arterial HOV Treatments*, begins with descriptions of arterial HOV lane types: concurrent flow, contraflow, and median lanes; transit malls, bus streets, and shoulder conversion. Operating characteristics of arterial HOV lanes, including queue bypasses, signalization, and Intelligent Transportation Systems (ITS) advances, are explored. The physical characteristics of arterial HOV lanes are also discussed, including reference to cross-sections, turning radii, and bus stop design. Part Two, *Freeway HOV Treatments*, begins by considering the perspective of those who see the very existence of HOV lanes that are open to both buses and carpools as evidence of erosion of an original commitment to transit. A discussion of occupancy policy as related to operational efficiency follows. The next section, on freeway HOV facility design, covers topics such as retrofitting as opposed to new construction, and basic HOV lane types, and their relative advantages. The issue of inside vs. outside HOV lane location is also discussed. Next, ramp types and designs are described, with reference to concerns such as gradients, clearance, transition lanes, and turning radii. A planning section covers cost-benefit analysis. The report concludes with sections on safety, enforcement, and the role of traffic management centers.

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CONTENTS

FIGURES

TABLES

INTRODUCTION

Confronted by worsening congestion and air quality, transportation agencies, elected officials, and stakeholders in urban areas the world over are turning to the high occupancy vehicle (HOV) concept in hope of finding at least a partial solution to these problems. Interest in HOV lanes has increased over the past decade and shows no sign of abating. In 1992, 378 lane miles of HOV lanes had been built; by the year 2000, this figure is expected to have risen to over 1,000 miles (fig. 1).

Thought to reduce the negative impacts of single occupant vehicle (SOV) travel by stressing person throughput over the traditional emphasis on vehicle throughput, HOV facilities offer ridesharel passengers travel time savings over the chief competitor—the SOV. HOV modes are thought to make more efficient use of existing roadway capacity by moving more people per vehicle trip. The ensuing reduction in vehicle trips, as well as congestion and cold starts, in turn reduces harmful emissions (Turnbull 1992; Dahlgren 1995).

Increased roadway and environmental efficiency are achieved at a relatively low capital cost, particularly compared to other capital intensive alternatives. Because HOV facilities are often created by retrofitting elements of the existing infrastructure, it is sometimes possible to avert the extremely high costs of acquiring additional right-of-way and major new construction. This is particularly important in suburban areas, where land use density is low, and where it is difficult and expensive to provide light or heavy rail transit service. A related advantage is that many HOV facilities may be implemented in progressive stages, thus minimizing disruption to the existing network and allowing the traveling public to enjoy their benefits more immediately.

While several authorities, most notably Fuhs (1990) and Caltrans (1991) have assembled comprehensive general resources on the design and operation of HOV facilities at large, none has yet done this from the perspective of transit. The lack of transit-specific research has left unanswered questions such as "What are transit's interests, and how are these interests best served in HOV facility design and operations?" In addressing these questions, the authors of this report have stitched together the pieces of available transit-related HOV research into what they hope is a coherent whole cloth.

In so doing, a wide range of sources has been considered, including numerous technical reports from around the United States and Canada on specific aspects of HOV facility design and operations, as well as discussions of HOV facilities' broader relationship to transit. The report covers technical aspects of HOV design and operations by dividing the domain into two principal components: arterials and freeways.

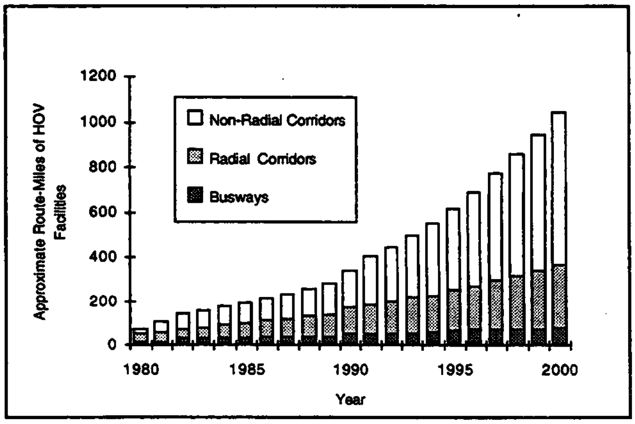


Figure 1. *Projected HOV lane miles. Source: Fuhs 1993*

PART 1

ARTERIAL HOV TREATMENTS

While the objectives of arterial and freeway HOV treatments are essentially the same—to bypass congestion and to provide HOVs with a travel advantage—HOV treatments on arterial streets are distinct from freeways in several respects, as identified by Jacobson, Ingalls, and Melone (1993):

- Buses on arterials must interact with pedestrians and bicyclists.
- Most buses on arterials stop frequently.
- Much of the delay for HOVs on arterials is due to signalized intersections.
- Arterial speed limits are lower.
- Arterial lanes may be narrower than freeway lanes.
- Arterials have fewer access restrictions than freeways.
- Through-traffic on arterials must compete with right- and left-turning vehicles.
- HOV enforcement on arterials is complicated by complex movements and usually limited enforcement areas.
- Arterial HOV facilities most often improve local access, as opposed to long-haul access.

In general, the conditions underlying planning and implementation of HOV facilities or priority treatments on arterials include a reasonable concentration of bus service, a high degree of bus and automobile congestion, and community support for public transit (Turnbull 1990). Table 1 presents general planning guidelines for assessing the applicability of various HOV facilities and priority treatments to arterial streets.

Arterial streets that are used exclusively by HOVs, or that have lanes dedicated to HOVs, feature many combinations of physical and operating characteristics—encompassing median type, the number of lanes dedicated to HOVs, lane location relative to the curb or median, and direction of flow (with or against general purpose traffic).

Following are general design guidelines for HOV facilities applicable to both arterials and freeways, prepared by McCormick Rankin (1994):

- Constructing a new HOV lane is more expensive than converting an existing lane.
- Re-striping can be used to add an additional lane as long as it does not decrease the widths of existing lanes to unacceptably narrow dimensions.
- An HOV lane should be no narrower than adjacent mixed flow lanes.
- Reversible lanes are applicable to corridors characterized by peak directional split in excess of at least 65/35 (peak/non-peak).

HOV LANE TYPES

Most of the literature on HOV lanes focuses on freeway HOV lanes. However, AASHTO (1992) includes a fairly detailed description of arterial HOV lanes. The discussion herein relies heavily on this important source.

There are four basic types of arterial HOV facilities: concurrent-flow curb lanes, contraflow curb lanes, median bus lanes and reversible median bus lanes, and bus streets (fig. 2) (AASHTO 1992). Three other treatments, queue bypasses, transit-preferential streets or lanes, and shoulder conversions, are also described.

Table 1. *General Planning Guidelines for Assessing the Applicability of Arterial HOV Treatments*

Treatment	General Applicability Local Bus	General Applicability Express Bus	Planning Period (yr)	Design-year Conditions One-way, Peak-hour Bus Vol.	Design-year Conditions One-way, Peak-hour Passenger Vol.	Related Land Use and Transportation Factors
Bus signal priority	✓	✓	1-5	10-15	400-600	Where signal priority control strategy satisfies requirements of traffic engineers and transit agencies
Special bus signals and signal phases, bus-actuated	✓	✓	1-5	5-10	200-400	At access points to bus lanes, busways, or terminals; where special bus turning movements must be accommodated
Special bus turn provisions	✓		1-5	5-10	200-400	Where vehicular turn prohibitions are located along bus routes
CBD curb bus lanes, main street	✓		5	20-30	800-1,200	Most appropriate in areas with commercially-oriented footage
Curb bus lanes	✓		5	30-40	1,200-1,600	At least two lanes for other traffic in same direction recommended
Median bus lanes	✓	✓	5	60-90	2,400-3,600	At least two lanes for other traffic in same direction recommended; may serve local buses if passenger boarding islands available
Contraflow bus lanes,	✓		5	20-30	800-1,200	
Contraflow bus lanes, extended	✓	✓	5	40-60 [a]	1,000-2,400 [a]	At least two lanes for other traffic in same direction recommended; signal spacing greater than every 500 feet
Bus turnouts off HOV lanes	✓	✓	5	81 or more	3,200 or more	Where bus volumes are high or dwell times are long, or where carpools, express, and local buses share
Bus bulbs	✓		1-5	No guidelines available	No guidelines available	May be used on bus-priority or bus-emphasis streets without exclusive bus/HOV lanes
Bus streets	✓	✓	5-10	20-30	800-1,200	Most appropriate in areas with commercially-oriented footage

Source: Adapted from Levinson 1975 and Transportation Research Board, Highway Capacity Manual (1992)

Note: a. Lower where carpools and local & express buses share lane. HCMs LOS E & F for CBDs for exclusive/near exclusive lanes

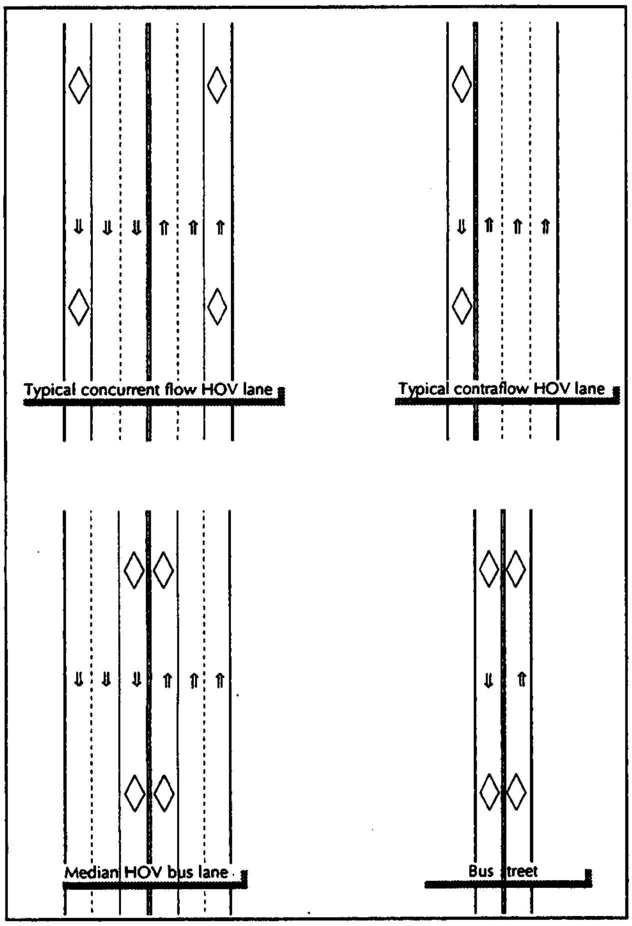


Figure 2. *Four basic types of arterial HOV treatments*

Concurrent Flow Curb Lanes

Concurrent-flow curb lanes travel along the curb with the traffic (fig. 3). The most common bus priority technique on arterial streets, they are usually implemented to improve local transit service (AASHTO 1992). Although concurrent-flow curb lanes are among the least expensive and simplest to implement, AASHTO (1992) recommends that whenever possible, a through-lane should be added to the roadway, rather than converting an existing lane to HOV use. If warranted by roadway conditions, this may be accomplished by converting parking lanes into HOV lanes, either all day or for part of the day.

To determine whether traffic conditions warrant a concurrent-flow lane, AASHTO (1992) recommends two primary criteria: that there be at least two remaining mixed-use lanes in the same direction of travel as the concurrent flow HOV lane; and that the number of people expected to use the HOV lane approximately equal the number expected to use the adjacent mixed-use lane (typically 20 to 40 local buses in the peak direction.).

Although safety problems posed by higher speeds in the HOV lane relative to adjacent mixed-use lanes are an issue primarily for freeway HOV lanes, they must be taken into account for arterial HOV treatments also. Accordingly, AASHTO (1992) recommends that speed differentials between concurrent flow HOV lanes and adjacent mixed use lanes in the same direction not exceed 10 to 15 miles per hour.

Turning movements. AASHTO (1992) recommends that where there is a right curb, concurrent flow HOV lane, right turns from general traffic should be made from the HOV lane or from a special turn bay constructed to the right of the HOV lane. Thus, general purpose traffic should be allowed to use the HOV lane for a short distance before the intersection to allow safe entry into the HOV lane for a right turn. AASHTO

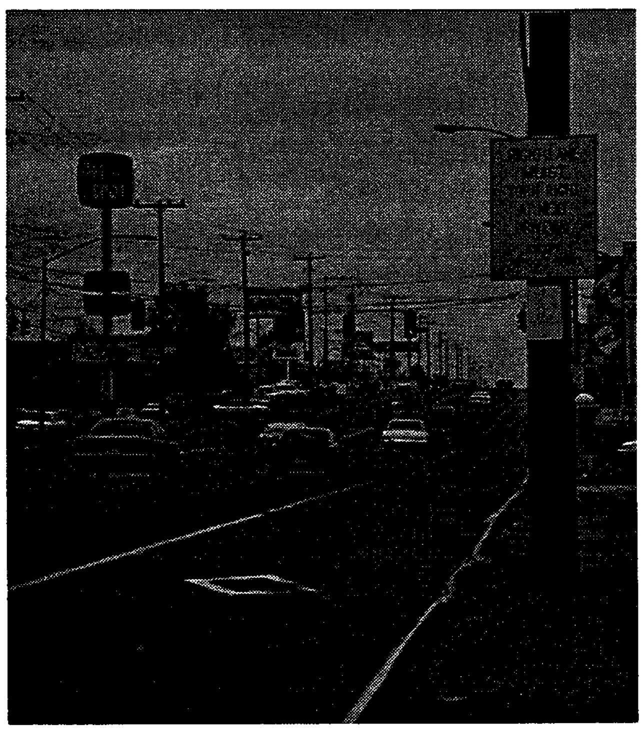


Figure 3. *Concurrent flow HOV lane in Seattle, Washington. General purpose traffic should be allowed to use the HOV lane for a short distance before the intersection to allow safe entry into the HOV lane for right turns.*

warns that right turns should never be allowed from an interior lane across the HOV lane.

Signalization and signing. Signalization techniques, such as bus signal priority and queue jumps, may be used in conjunction with concurrent flow curb HOV lanes. Concurrent flow HOV lanes should be distinguished from general purpose traffic by a solid white line and pavement markers (Levinson, Adams, and Hoey 1975).

Hours of operation. Concurrent-flow curb HOV lanes may be reserved for buses all day or during peak periods only. Lanes may be maintained all day where off-peak bus volumes exceed the minimum hourly warrant, or where transit prioritization is desired (Levinson, Adams, and Hoey 1975). The advantage of all-day operation is that enforcement may be simpler, and that the lanes provide priority treatment to buses throughout the day, when atypical congestion may occur.

Contraflow Curb Lanes

Contraflow lanes allow buses to run against normal traffic flow on one-way streets (fig. 4). Because automobile drivers are not accustomed to driving on this type of facility, contraflow lanes are normally restricted to buses. In fact, drivers would need special training to prevent operational and safety problems (AASHTO 1992). An advantage of contraflow bus lanes is that they are highly visible, and as such, largely self-enforcing (Levinson, Adams, and Hoey 1975).

Contraflow facilities may be developed in three ways: (1) a contraflow lane may be added to an existing one-way arterial; (2) a two-way street may be converted to one-way flow, with HOVs continuing to use the street in the contraflow direction; or (3) a lane may be added to a divided arterial by using an off-peak direction lane (left of the median) for peak-direction travel (TTI 1990).

Because buses traveling in contraflow lanes are separated from other traffic, they are removed from conflicts with other vehicles and from peak-hour congestion at signalized intersections (Levinson, Adams, and Hoey 1975). By taking advantage of unused capacity in the off-peak direction, contraflow treatments can improve local transit service, or increase capacity (AASHTO 1992).

Contraflow lanes designed to take advantage of unused capacity are practical only where an acceptable level of service can be maintained in the off-peak direction. According to AASHTO, this usually corresponds to a directional split of at least 60/40, but preferably 65/35. This split is less critical on one-way pairs than on two-way streets. Contraflow lanes may range from very short segments in central business districts to very long seg-

Figure 4. *Spring Street, a contraflow HOV arterial in downtown Los Angeles*

ments along radial arterials (AASHTO 1992). Contraflow HOV lanes' unexpected traffic pattern necessitates special pedestrian safety precautions. Contraflow lanes should be accompanied by at least two lanes of general traffic in the opposite direction, or one lane on very short segments, provided that the single lane has enough capacity for traffic in the off-peak direction, and that no bottleneck is created (AASHTO 1992).

Curbside parking, standby taxis, and deliveries must be restricted during the hours of curbside contraflow HOV lane operation. On facilities where local deliveries are unavoidable, and where the street is wide enough, a two-lane contraflow configuration may allow deliveries in the curb lane during non-peak hours, provided that delivery trucks use contraflow lanes only on the blocks where they are making a delivery (AASHTO 1992).

On one-way streets, bus lanes may be placed along the right curb or along the left curb (from the perspective of the bus). However, the left curb lane cannot normally be used for passenger boarding, unless boarding islands are provided or unless bus doors are added. On one-way streets, it is more common to use the right curb (AASHTO 1992). Contraflow lanes should be distinguished from general traffic by overhead signage (e.g., "KEEP RIGHT," "DO NOT ENTER," "WRONG WAY").

Turning movement restrictions. On one-way streets, turning movements by general traffic across the contraflow HOV lane can usually be permitted without restriction, unless HOV volumes are very high (AASHTO 1992). To enhance safety, intersections may be equipped with special signs alerting drivers to watch for opposing traffic in the HOV lane. When buses must turn across general traffic from contraflow lanes, they should do so only at intersections where traffic signals provide buses protected turning phases. Turning restrictions for contraflow lanes on two-way streets are described in AASHTO (1992).

Contraflow lanes on one-way streets require separate signals, to include special turn phases if turns from contraflow lanes across other lanes of traffic are permitted (AASHTO 1992). A typical signal timing plan in dense downtown areas with near-side bus stops is a counter-progression system that turns red just as the bus arrives at the signal, then turns green as bus loading is completed. Such timing may provide a better level of service in both directions. In addition, where opposing left turn traffic is blocked by heavy pedestrian flows, a short leading green phase for the contraflow lane may be desirable (AASHTO 1992).

Hours of Operation. Contraflow bus lanes should operate throughout the day. However, operation may be restricted to peak periods, as long as curb parking is permitted in the bus lane during the off-peak (Levinson, Adams, and Hoey 1975).

Median Bus Lanes

Historically rooted in streetcar operations, median bus lanes' advantages are that they are removed from traffic conflicts along the curb, and that they allow right turns to be made without conflicting with buses (Levinson 1975). Median bus lanes' disadvantage is that they only work well for express bus service, as opposed to local service, unless boarding islands are constructed in the middle of the roadway. Boarding islands may be problematic because they require passengers to cross moving traffic to reach the islands. Another disadvantage of median bus or HOV lanes is that left turns in the direction of travel of the median lane must be prohibited or controlled to minimize interference with buses (Levinson, Adams, and Hoey 1975; AASHTO 1992). AASHTO notes that median HOV lanes range in length up to several miles, and may have one or two lanes that are 12 ft wide (11 ft minimum). Length depends on the lane's purpose (e.g., express vs. local service) and on transit routing patterns. Wherever possible, median HOV lanes should be physically separated from general purpose traffic by raised islands, painted buffers, permanent traffic barriers, or channelizers.

Transition areas and points of access. Three typical transitions from median bus or HOV lanes to general purpose lanes are suggested (AASHTO 1992). In the first type (fig. 5A), the right general purpose lane is dropped, and HOVs and buses continue straight through in their own lane, which becomes a general purpose lane. In the second type (fig. 5B), a bus or HOV lane ends,

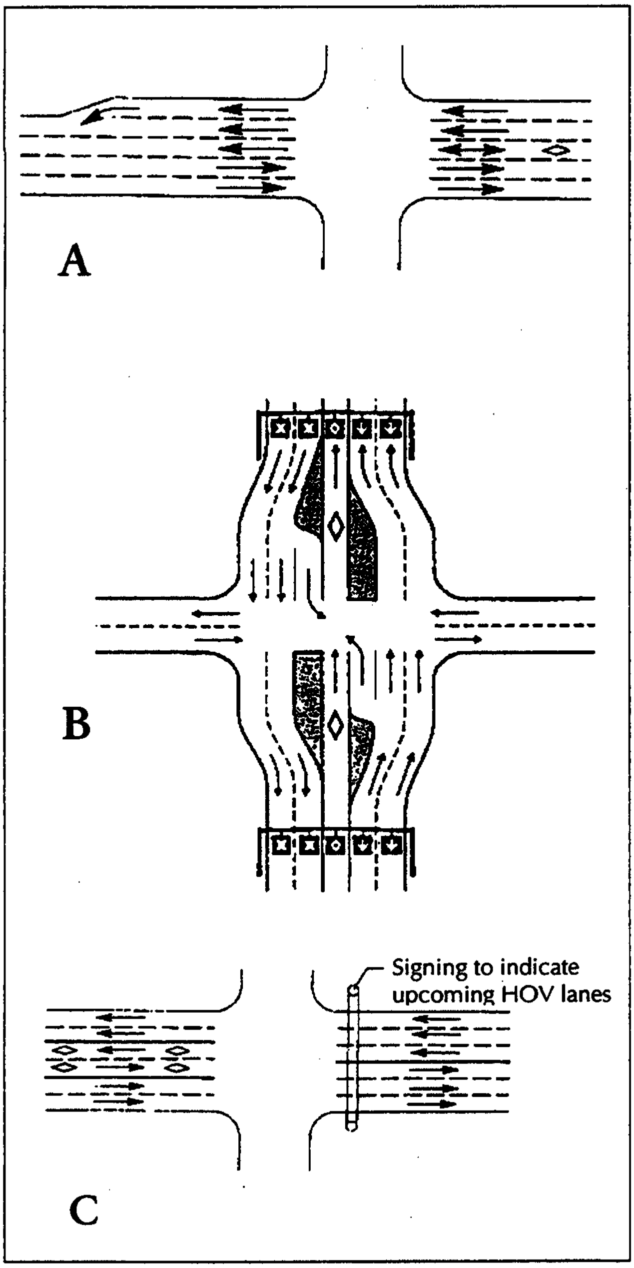


Figure 5. *Transitions from general purpose lanes to median Bus/HOV lanes.* **(A)** *In this type of median HOV lane, the right general purpose lane is dropped, and HOVs and buses continue in their own lane, which becomes a general purpose lane* **(B)** *In this type of median HOV lane, the HOV lane ends, and buses traverse to the right into the general purpose lane* **(C)** *In this type of median HOV lane, no lanes are dropped, but advance signing indicates the change from general purpose to HOV lane Source: American Association of State Highway and Transportation Officials (1992)*

and then buses traverse to the right into general traffic lanes. In this case, AASHTO recommends that the traffic signal provide a separate signal phase (queue jump) to allow buses to move into the general traffic lanes more easily. The third type (fig. 5C) is one in which no lanes are dropped, but advance signing indicates the change from general purpose lane to HOV or bus lane.

Reversible Median Lanes

If only one lane is available for HOV use, it is possible to use that lane for HOV travel in the peak direction, reversing the direction of travel from a.m. to p.m. Such configurations are called reversible median lanes. The direction of the lane may be indicated with signal control (fig. 6). The advantage of reversible HOV lanes is that insofar as they provide for two-way HOV travel with only one lane, they require much less right-of-way. The primary disadvantage is that traffic control can be confusing—with serious safety implications (PBQD 1994).

Turning movements. Left turns in the direction of travel of the median bus lane must be prohibited or controlled to minimize interference with buses (Levinson, Adams, and Hoey 1975; AASHTO 1992). Where left turns cannot be prohibited, they should be allowed at selected intersections only with special left-turn-only signal phases. Right turns by general traffic do not affect buses in median lanes (AASHTO 1992).

Signing and Signalization. AASHTO recommends that signage for bus or HOV-only lanes follow MUTCD guidelines, and that signs be placed at all access points as well as periodically along the length of the lane. Signs on median bus lanes that are not separated from mixed-use traffic lanes by a physical barrier should be placed more frequently.

AASHTO recommends separate signalization for median HOV or bus lanes at all intersections. In addition, median bus/HOV lanes may be given special signal phases (e.g., left turns for buses only) to give buses priority. Buses making right turns typically leave the median lane before reaching the intersection, weaving across mixed-use lanes to complete their turns (AASHTO 1992).

Hours of operation. Median lanes should generally operate all day, although it is possible to operate median lanes during peak periods alone (Levinson, Adams, and Hoey 1975).

Bus Streets or Transit Malls

Some cities, including Portland, Vancouver, B.C., Minneapolis, and Honolulu, have dedicated entire streets to buses (PBQD 1991). Bus streets (or transit malls) are usually located where several bus routes converge, in central business districts, or in areas with heavy pedestrian volumes. They tend to improve circulation in congested areas rather than cutting travel times for long-haul bus routes; as such, bus streets serve local routes primarily (AASHTO 1992).

Dedication of a street to buses is a major commitment to downtown transit and development (Levinson, Adams, and Hoey 1975). Bus streets fully separate bus and automobile traffic, increase transit reliability, enhance transit identity, and provide downtown distribution for regional express routes. Bus streets may also enhance the pedestrian environment by allowing conversion of extra lanes into wider sidewalks with improved landscaping (AASHTO 1992). Bus streets may also serve bus terminals, bus loops, short connecting links, and auto-free zones (fig. 7) (AASHTO 1992). Although AASHTO recommends that a minimum of 20 buses use the bus street in each direction during the peak hour, this figure is flexible, and actual use criteria will depend on project objectives.

The *Canadian Transit Handbook* enumerates some of the objectives of bus-only streets (Canadian Urban Transit Association and the Roads and Transportation Association 1985):

- Providing a means by which people may use transit to reach the city's most popular destinations without having to walk too far upon arrival
- Maximizing pedestrian safety in shopping areas and other attractive destinations
- Improving interchange facilities between bus routes by creating a more attractive environment for transfers
- Improving bus reliability and reducing delays
- Improving the environment of streets used intensively by pedestrians by removing unnecessary traffic and thereby reducing noise, fumes and visual intrusion

Bus streets should generally operate in both directions to provide passenger loading and unloading on the same street. Most bus streets require no more than a single lane in each direction if the street is not divided.

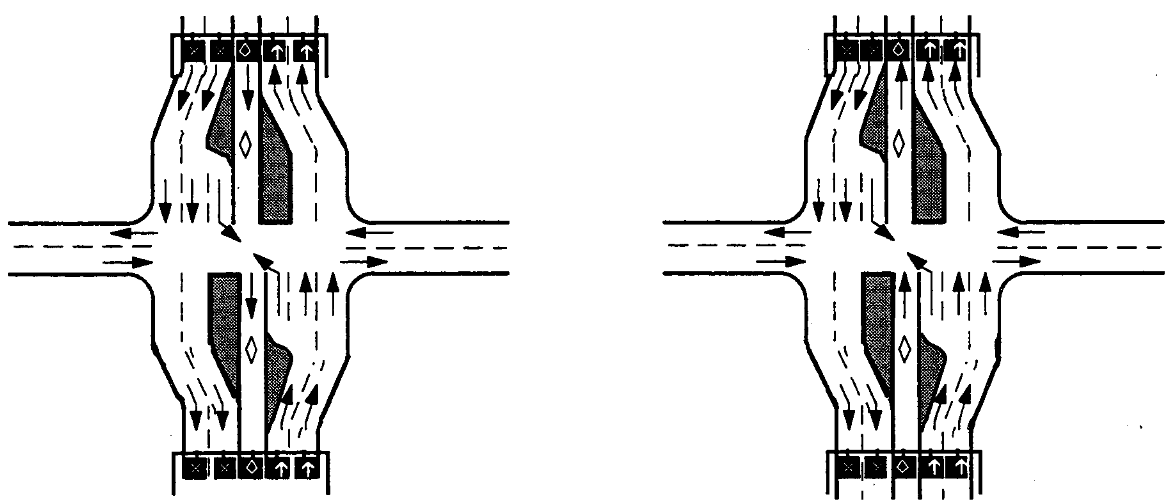


Figure 6. *Reversible median lanes with signal control. Source: Parsons, Brinckerhoff, Quade and Douglas, Inc. (1994)*

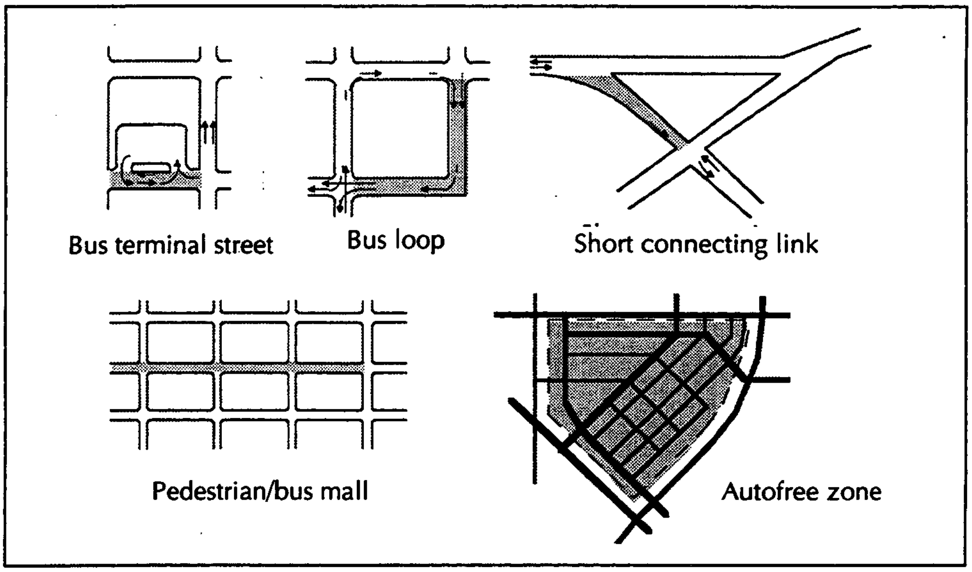


Figure 7. *Bus streets, which fully separate bus and automobile traffic, serve a variety of functions.*
Source: American Association of State Highway and Transportation Officials, (1992)

Bus turnouts may be provided when warranted by bus volumes and dwell times. AASHTO (1992) recommends the guidelines in Table 2 for a typical bus street.

Transition areas. Automobiles and other non-HOVs must be diverted from bus streets. AASHTO recommends that vehicles other than buses be diverted from bus streets by right or left turns at the intersections preceding the bus street, with required turning signs, delineation, and signal indications (1992). It may be necessary to widen some cross-streets to accommodate large turning volumes (AASHTO 1992).

Turning movements. If a bus street is short (i.e., under three to four blocks), elimination of cross movements and intersection turning movements may be desirable. However, before restricting traffic movements, access impacts on properties on side streets should be evaluated (AASHTO 1992).

Signing and signalization. AASHTO recommends the use of preferential lane markings (diamond symbols) together with restricted lane signs (1992). All access points should also be equipped with appropriate signage to control access and turns. Bus streets are particularly well suited for signal preemption systems.

Hours of operation. Where suitable alternative access is unavailable, bus streets may be opened to service vehicles (e.g., delivery trucks) at night and possibly during the off-peak (Levinson, Adams, and Hoey 1975). Some jurisdictions allow cabs, emergency vehicles, and other service vehicles onto bus streets any time of day.

Transit-Preferential Streets or Lanes

On many arterials, exclusive HOV or bus-only lanes or streets may not be feasible because of financial or geometric constraints, because they do not serve the arterial's

	One-way Reserved Street	Two-way Reserved Street
Low Bus Volumes (< 30 buses per hour)	20 ft wide minimum	24 ft wide minimum
Moderate Bus Volumes (30 - 100 buses per hour)	24 ft wide minimum	30 - 40 ft wide
Very High Bus Volumes (> 100 buses per hour)	24 ft wide minimum, bus turnouts provided	40 ft wide minimum, bus turnouts provided

Source: American Association of State Highway and Transportation Officials (1992)

Table 2. *AASHTO Lane Width Guidelines for Bus Streets*

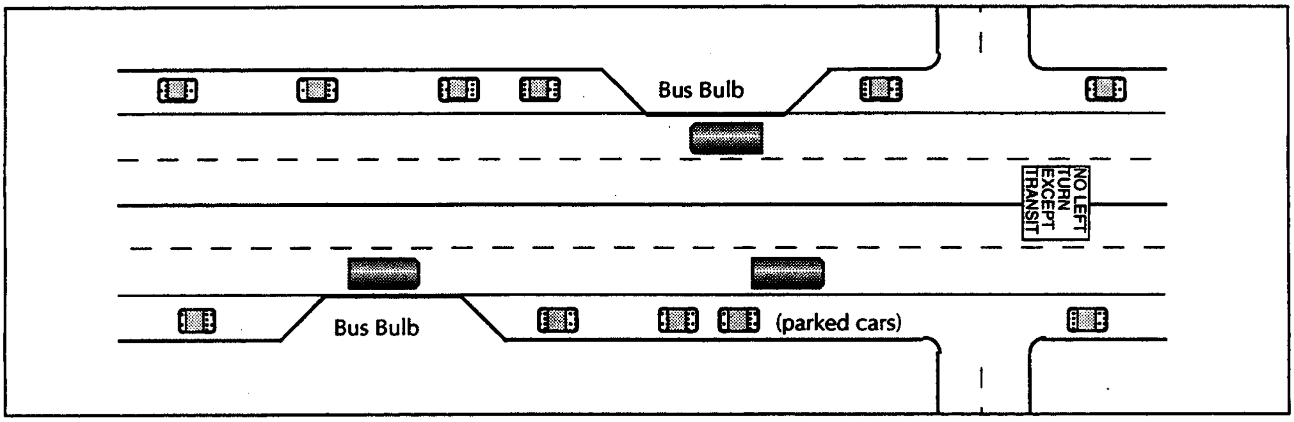


Figure 8. *Possible features of a transit-preferential street*

objectives, or because of public resistance. In such cases, transit-preferential streets or lanes may be more realistic. The objective of transit-preferential facilities is to create an environment where buses and automobiles share road space, but where selected lanes are transit-friendly, as opposed to automobile-friendly. Transit preferential streets may entail the following features, some of which are shown in figure 8.

- Bus bulbs used as bus stops
- Bus prioritization at traffic signals
- Queue bypasses for transit
- Special turns for transit only

Converting Shoulder Lanes to Bus Lanes

Arterial and highway shoulders are sometimes converted to bus-only use, all day or during peak periods (fig. 9). AASHTO stresses that where possible, a through-lane should be added, rather than converting an existing lane (1992). However, lane addition is often impossible because of right-of-way constraints. If the parking lane is used as an HOV lane, then curbside parking, taxi service, and commercial deliveries must be restricted during HOV lane hours of operation.

The advantages of converting shoulders to bus-only lanes are that implementation is relatively quick and inexpensive, and that it can effectively reduce travel time for buses (Metropolitan Transit Commission 1994). The disadvantage of shoulder lanes is that they eliminate the shoulder, which raises safety and traffic issues.

Figure 9. *A state route in the metropolitan Seattle area the shoulder of which has been converted to HOV use*

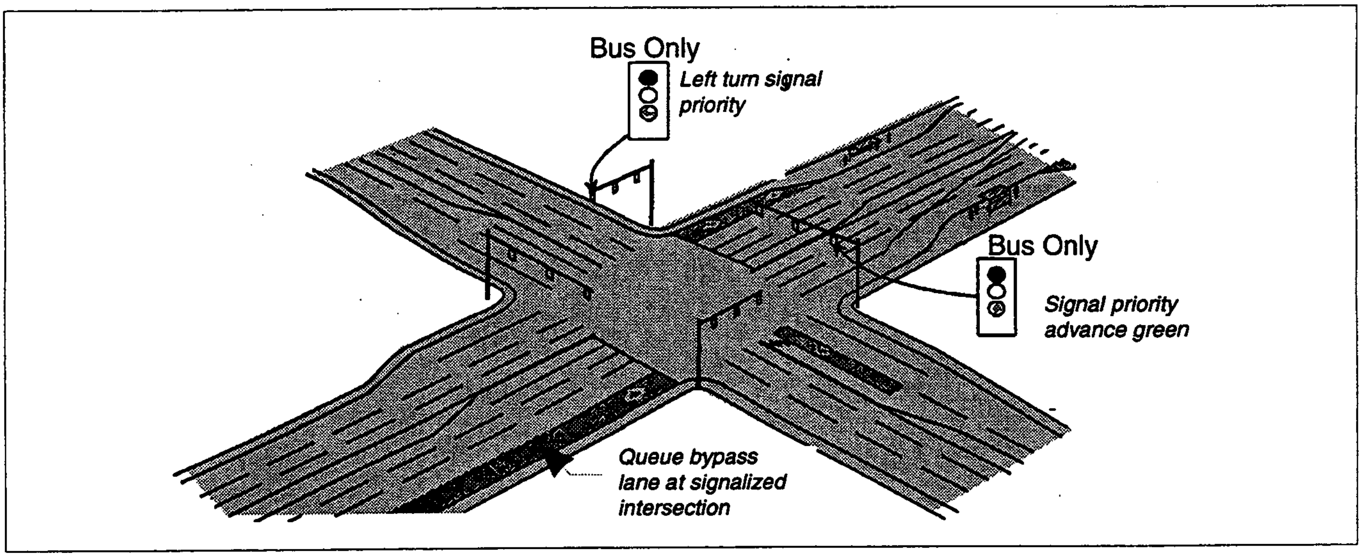


Figure 10. *A queue bypass designed to provide an HOV advantage. Source: Parsons, Brinkerhoff, Quade & Douglas, Inc. (1993)*

OPERATING CHARACTERISTICS OF TRANSIT-PREFERENTIAL FACILITIES

Buses spend much of their time stopped at traffic lights. Several studies focusing on German cities found that the percentage of total travel time buses spent stopped at traffic signals was 43.5 percent in Braunschweig, 27.9 percent in Lippstadt, and 30.7 percent in Bochum (Brilon and Laubert 1994). These figures suggest that priority treatment for buses at traffic signals has the potential to reduce transit travel times, and to improve schedule reliability. Traffic signal phases can sometimes be adjusted to provide preferential HOV treatment. HOVs can be given a jump ahead of other traffic, or they can even be allowed to make left turns from a curbside HOV lane. Figure 12 presents some options for preferential signal phasing for HOVs on facilities with HOV or bus lanes.

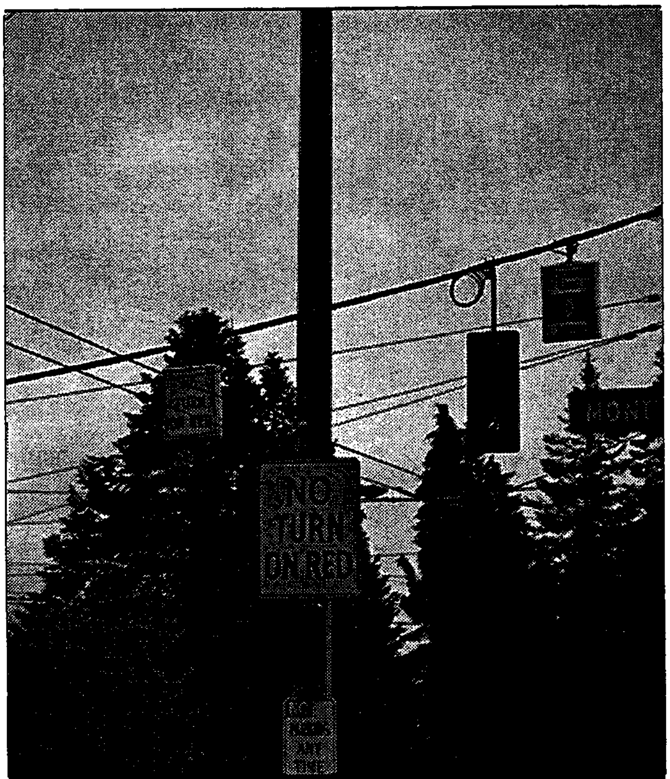


Figure 11. *Signal queue jump at Seattle's Montlake Boulevard*

Queue Bypasses

On arterials where it is not possible to run an HOV lane along the length of the facility, it may instead be feasible to use queue bypasses at selected locations. Queue bypasses are short segments of roadway dedicated to HOV and transit use exclusively (fig. 10). Short queue bypasses can be effective in allowing HOVs to bypass bottlenecks, or to proceed through intersections ahead of other traffic.

Signal Queue Jumps

A signal queue jump is like a queue bypass, except that it also gives a special signal phase for the bus (fig. 11). In such applications, a separate bus-only through movement phase can precede other through movement phases. An additional merge lane downstream of the intersection allows buses to re-enter the traffic stream, thus enabling them to bypass bottlenecks (fig. 13A).

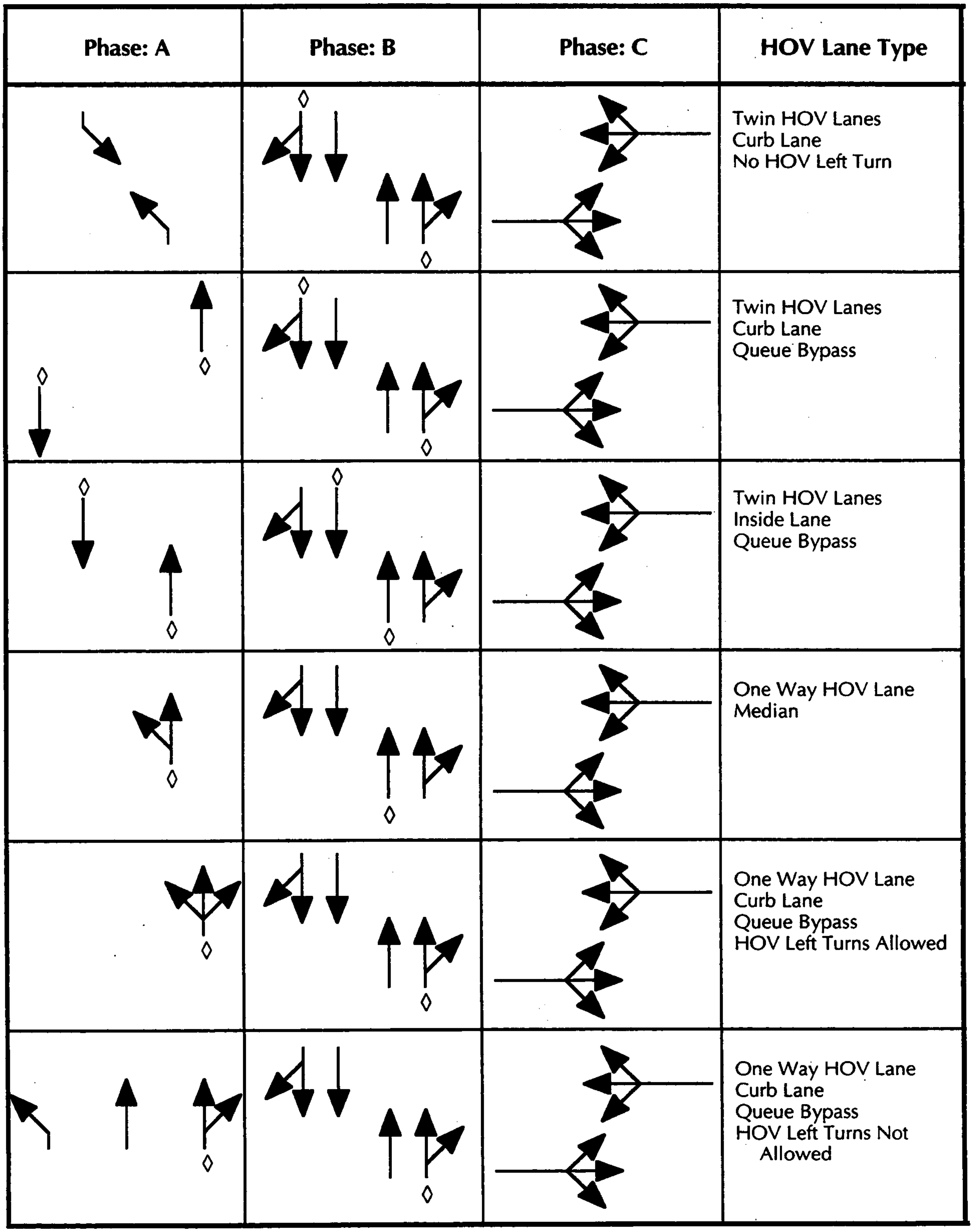


Figure 12. *Options for preferential signal phasing on facilities with HOV or bus lanes. Source: McCormick Rankin (1994)*

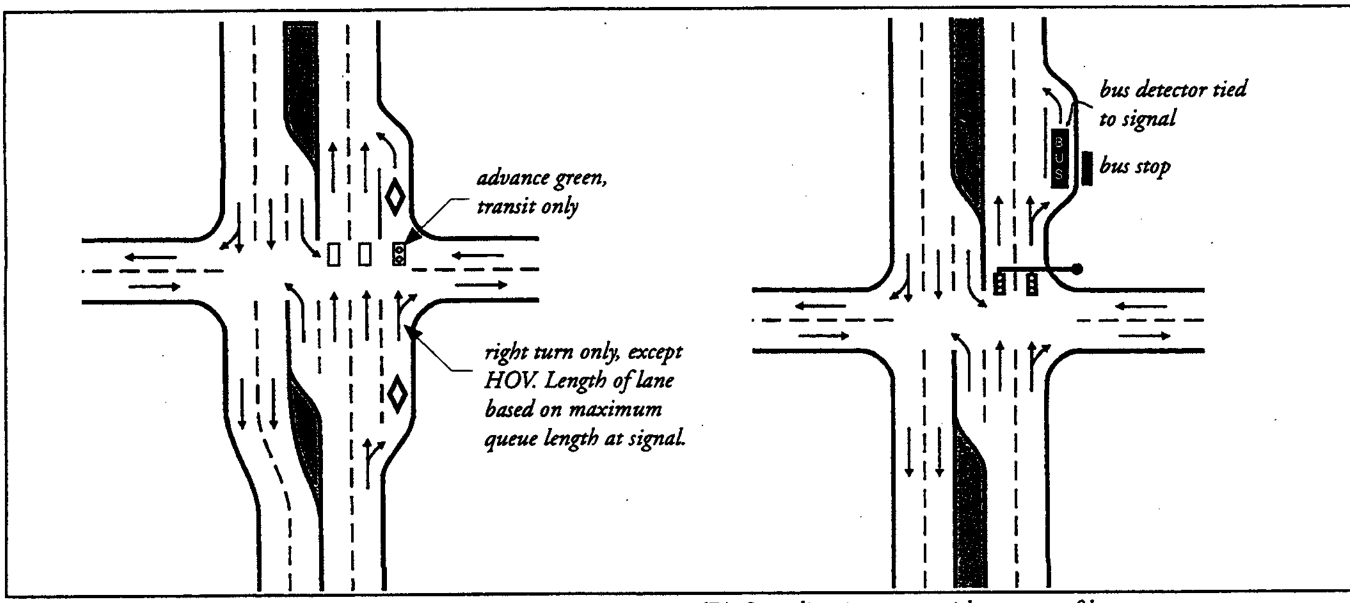


Figure 13 (A) *Signal queue jump* (B) *Signalization to provide reentry of buses at turnouts*
Source: Parsons, Brinkerhoff, Quade and Douglas, Inc. (1994)

BUS PRIORITY REENTRY INTO THE TRAFFIC STREAM

On roadways without HOV or bus lanes, the primary disadvantage of bus turnouts is that they make it difficult for buses to re-enter the traffic stream after stopping to board passengers. However, this disadvantage can be mitigated. Where bus turnouts are far-side, it may be possible at some intersections to design the bus turnout and signalization system to allow buses to re-enter the traffic stream more easily. Detection of the bus at the turnout may trigger the traffic signal to hold traffic while the bus re-enters the traffic stream (fig. 13B) (PBQD 1994).

Bus Priority Gating

Bus priority gating, a strategy very much like queue jumps, creates bus advance areas by stopping non-priority traffic at a secondary stop line (called the pre-signal stop line), while allowing priority traffic to proceed directly to the main stop line (Roberts 1995). Shortly before the main signal turns green, the pre-signal turns green to release non-priority traffic to allow full use to be made of the main signal's green phase.

Bus priority gating and advance areas (figs. 14 and 15) can accomplish several objectives: (1) they can be used when a bus lane is ending to enable buses to re-enter the traffic stream, (2) they can be used to allow buses to jump to the front of a queue at a traffic signal after they have picked up passengers at a bus stop, and (3) they can allow buses to jump ahead of other traffic to cross over lanes to reach the left-turn lane without obstruction. This treatment can also be used to give buses priority at mid-block traffic signals, such as at controlled pedestrian crossings. In addition, where a curbside bus lane at an intersection is "shared" by other vehicles so that they can make turning movements, a signal controlled bus advance area can allow buses to reach the intersection before non-priority traffic.

Signal Priority

Transit signal priority systems are not new, dating back to as early as 1974 in Washington, DC. Over the next decade, implementation of transit signal priority systems progressed throughout the nation. However, many early systems were discontinued for the following reasons: (1) new control strategies that better addressed traffic volumes replaced some priority systems, (2) alternative preferential transit treatments were implemented with greater benefits at some locations, and (3) delay on cross-streets forced abandonment of some priority systems.

Surprisingly little is known about the "best" way to integrate transit signal priority into network-optimized traffic signal systems. Test results of transit signal priority systems are mixed (Table 3). Benefits were found to vary significantly among intersections, suggesting that dynamic traffic conditions (e.g., total volume, LOS at the intersection, etc.) heavily influence the priority system's success.

Signal Timing Plans Over the Years

While there are countless way to adjust traffic signal timing plans to favor transit vehicles, two methods have predominated over the past 20 years: (1) green extension/red truncation, and (2) the lift strategy.

Green extension/red truncation works on the following principle: If a transit vehicle encounters a red light in the priority direction, then the traffic controller will return a green light at the earliest opportunity. Selected intersections may allow for skipping of certain phases altogether if the delay is minimal.

The lift strategy is compatible with actuated traffic signal systems only. The lift strategy functions by temporarily ignoring (lifting) other actuations until the transit vehicle passses, at which point the traffic control system returns to normal actuation operations.

The simple green extension/red truncation and lift strategies are both candidates for modern signal priority treatments, especially when additional information is included in the decision tree used to select whether and how that priority is given. Such information would answer questions such as the following: How many buses have recently been given priority treatment? Is the signal network operating near saturation levels? What is the current status of stop/bar detectors and/or volume count from upstream system detectors? In essence, adding real-time information on the status of nearby roads and intersections holds promise for yielding more efficient signal priority decisions.

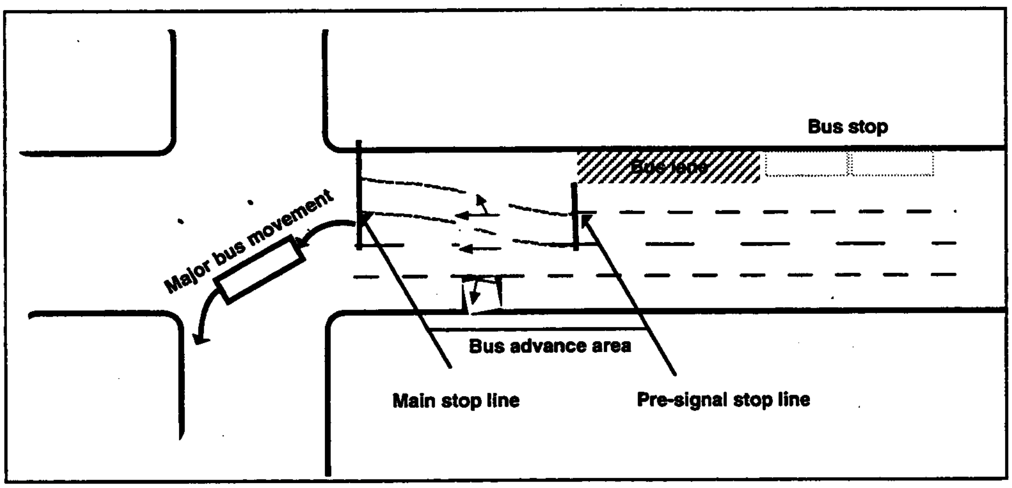


Figure 14. *Bus priority gating and advance area to enable buses to turn left. Source: Adapted from Roberts (1995)*

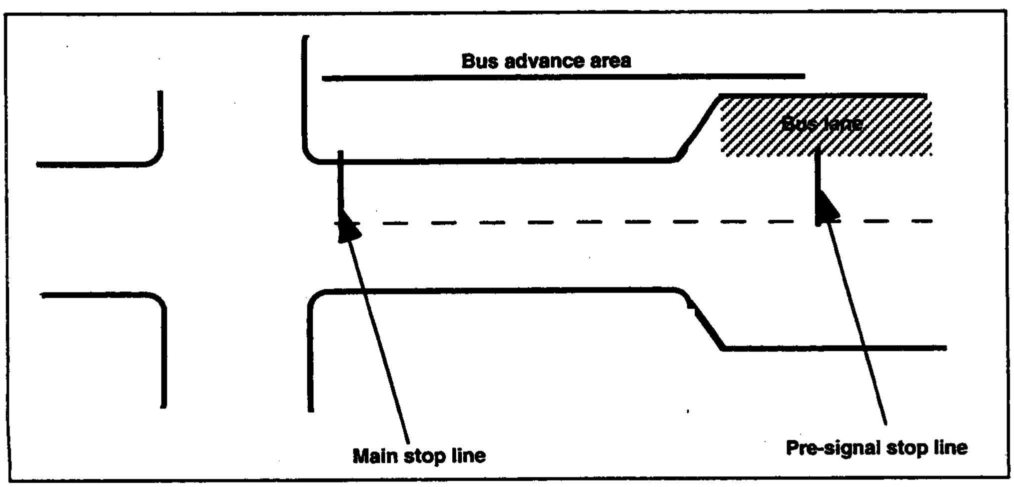


Figure 15. *Bus priority gating and advance area where bus lane ends. Source: Adapted from Roberts (1995)*

In addition to extensions of the "traditional" signal priority techniques, a variety of adaptive algorithms have been suggested as improved decision making criteria. Adaptive prioritization schemes are key given the trend toward more adaptive traffic signal control. Optimized Policies for Adaptive Control (OPAC) and the Signal Priority Procedure for Optimization in Real-Time (SPPORT) are two of the most promising adaptive algorithms.

OPAC is an on-line signal timing optimization algorithm that shows potential for handling the additional processing requirements of a transit signal priority system (HOV-weighted OPAC). Currently under investigation, one version of the system's operation would function as follows: AVI would be used to identify the arrival of a priority transit vehicle. The vehicle would be weighted (e.g., 1 priority vehicle equals 10 non-priority vehicles) and included in the normal control algorithm. Weighting each vehicle by the average occupancy would cause the algorithm to minimize person delay rather than vehicle delay. A second approach would be for a priority transit vehicle to trigger a preemption algorithm wherein current signal timing phases would have been adjusted to minimize transit delay. OPAC field tests are underway in the greater Seattle area.

One shortcoming of the existing OPAC control algorithm is that it is an isolated intersection control strategy, which is not currently applicable to arterials or networks, although some work refinement of the basic OPAC adaptive system for use in arterial control has been done. In addition, the OPAC algorithm could be tested as part of the decision criteria as to whether to grant signal priority to a transit vehicle at an intersection. If priority is to be given, then the mechanism used to adjust the timing plan might be determined by means of a more traditional method.

SPPORT generates and selects signal plans in real-time using simple, generic lists of rules that allocate specified priority levels for traffic events. Once a vehicle is detected, the control algorithm determines its priority and maintains a list of recently-detected vehicles. An event-based approach then models vehicle movement through the intersection. An event is defined as the arrival or departure of a vehicle.

Next, the algorithm generates and selects signal timing plans based on available data (updated at least every 90 seconds). More specifically, the control algorithm estimates delay, defines an ordered list of priority events, selects the appropriate signal timing plan, and begins evaluating candidate switching plans (Yagar and Han 1994). Yagar and Han suggest that the SPPORT is superior to OPAC because SPPORT relies on discrete rather than dynamic information, which allows it to model events such as transit passenger loading and unloading delays more accurately.

Further improvements in incorporating transit signal priority into adaptive signal control systems are recommended by Chang, Vasudevan, and Su (1995), who recommend basing the traffic control strategy on a performance index, to include vehicle, bus schedule, and passenger delay. Made up of three components: (1) a traffic state estimation module, (2) a signal state estimation module, and (3) a bus preemption module, this control strategy proved superior to actuated control logic when real-time traffic variables from the output of TRAF.NETSIM were used to test the algorithm's performance. Chang, Vasudevan and Su (1995) attribute the algorithm's success to its consideration of schedule delay for transit vehicles.

Bus signal priority can be passive or active. Passive systems involve favoring buses at signalized intersections by adjusting signal timing or reordering signal phases. These systems do not detect buses at intersections; rather, timing patterns are created based on historical data or bus schedules (Skabardonis, Deakin, Harvey, and Stevens 1990). Active systems, on the other hand, detect the buses near traffic signals and alter signalization to favor them.

Passive Systems. A relatively low-cost approach to transit prioritization is to develop optimized, fixed-time plans weighted to favor movements that include transit vehicles. The drawback of developing such plans to favor transit is that they cannot account for changes in bus volumes or routes, which could render the timings ineffective (Skabardonis, Deakin, Harvey, and Stevens 1990). Moreover, if transit peak hours do not correspond with those of general traffic, it may be difficult to develop timing plans that will help both transit and general traffic. (However, signals that can implement many timing plans or change

Table 3. *Findings from Bus Signal Priority Studies*

Year	Project	Bus travel time/delay	Automobile travel time delay	Cross-street intersection delay	Summary of Results
In Use	Bremerton, Washington	✓		✓	Bus travel time decreased 5% to 16% with signal preemption; impact on cross-street traffic not fully understood
In Use	Amsterdam, Netherlands	✓		✓	Travel time reduced by 7% to 12% for trams
In Use	Charlotte, North Carolina	✓			On one bus route segment, travel time decreased from 11 minutes to six minutes
In Use	Anne Arundel County, Maryland	✓			Uses bus signal priority at intersections and queue jumps (allows buses about ten second jump start); other impacts under study
1989	Ventura Boulevard, California	✓			Bus delay at intersection decreased by 21.6 %; bus travel time decreased by 4.23%; fuel consumptior also decreased
1983	Toronto, Ontario	✓			Travel time savings for streetcars ranging from 6% to 20%
1981	Memphis, Tennessee	✓	✓	✓	Small sample size notwithstanding, findings suggest that bus and auto travel time and delay (cars traveling on same street) decreased; study of intersection delay was inconclusive
Early 1980s	Dallas, Texas	✓	✓		Average bus travel time decreased by 5% to 17%
1978	Concord, California	✓	✓	✓	Bus travel time decreased by 9% auto travel time and delay did not change significantly on main or side streets
1977	Bell Street, Australia	✓	✓	✓	Bus travel time and delay decreased; automobile delay at intersection increased slightly
Early 1970s	Kent State University, Ohio	✓	✓		Bus speeds increased by an average of 10%; auto travel time and delay (on same street) decreased

Source: Adapted from Williams et al. (1993)

timing plans from a master controller may be able to deal with this adequately.)

Fixed timing plans favoring transit are generally more useful for express buses than for local buses. Because local buses stop frequently, and because dwell times may be long, arrival time at intersections may be highly variable, making it difficult to engineer fixed timing plans to favor transit (Skabardonis, Deakin, Harvey, and Stevens 1990).

Another method of passive priority is to adjust signal phases to favor transit on roadways with HOV-only lanes or queue bypasses.

Active Systems. Active bus priority systems involve the detection of buses and bus-activated signals. Such systems, which require special bus equipment, provide priority by electronically altering signal timing to favor buses. While bus signal priority is used in many European cities, including Osnabrück, Wiesbaden, Saarbrücken, and Hannover, Germany; Zürich, Switzerland; and Amsterdam,

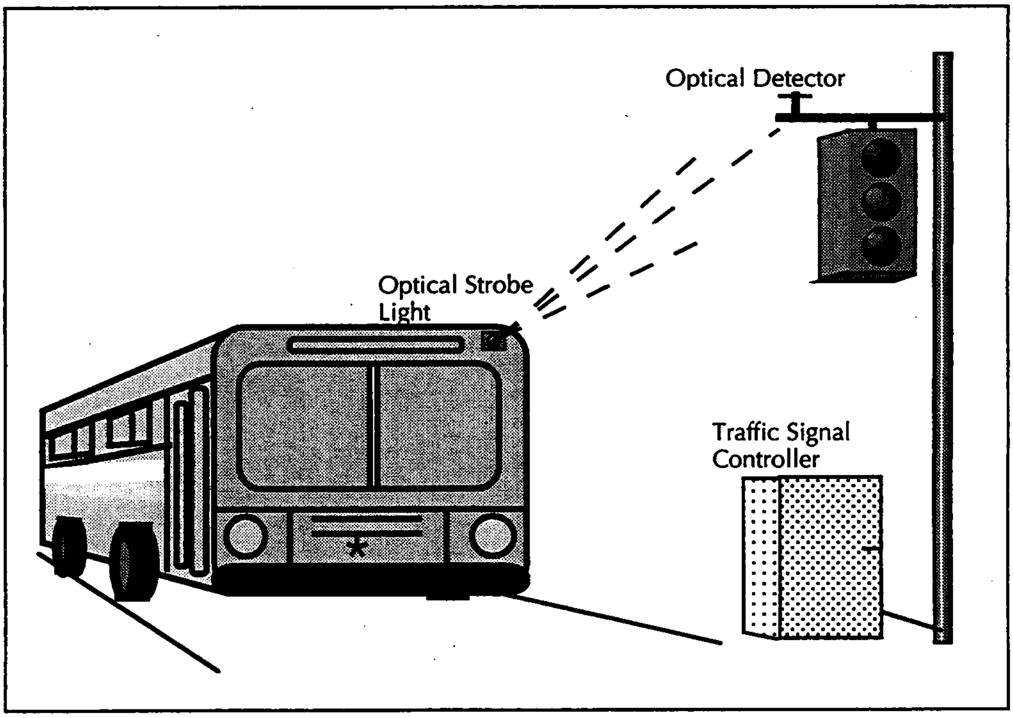


Figure 16. *Opticom Priority Control System for buses*

Netherlands (Chicago Transit Authority 1992), it has not been implemented as widely in the United States. In the 1970s and 1980s, a number of bus signal priority/preemption studies were conducted, some results of which are included in Table 3. For the most part, researchers found that priority for buses reduces delay and travel time slightly to moderately, but that it also has the potential to impact cross-street traffic negatively (Williams, Haselkorn, and Alalusi 1993).

Bremerton, Washington, is currently using 3M's Opticom Priority Control System (fig. 16), a second priority signal preemption system that automatically grants first priority to emergency vehicles at 43 of the city's 45 traffic signals (Williams, Haselkorn, and Alalusi 1993).

The Opticom's primary components are a strobe light that may be installed either inside or outside of the bus; an optical detector, which reads signals from the strobe light; and a traffic signal controller. As a bus approaches the intersection, the driver turns on the strobe light. The optical detector then reads the signal and, in most cases, attempts to turn the traffic light green for the bus. However, if an emergency vehicle approaches from the cross-street, then the signal immediately changes green Most of Bremerton's intersections are two-phase. The system software is designed so that the traffic signal falls back into synch with signal coordination within 30 seconds of preemption. However, on intersections that have more than two signal phases, certain signal phases may be skipped in the system's attempt to restore coordination (Williams, Haselkorn, and Alalusi 1993).

Bus signal prioritization in Bremerton, Washington, was found to reduce bus travel time by five percent to 16 percent (depending on route). Findings on cross-street traffic impacts were inconclusive (Williams, Haselkorn, and Alalusi 1993). Other jurisdictions using or testing bus signal priority include: Tacoma, Washington (Funkhouser 1996); Charlotte, North Carolina (Finger 1993); Anne Arundel County, Maryland (Hood 1994); and St. Paul, Minnesota (Metropolitan Transit Commission 1994).

Critical elements in bus signal priority systems are the detection equipment (most commonly a form of Automatic Vehicle Identification (AVI) and the signal control strategy. Such a strategy determines how a traffic signal responds to a request from a bus for priority. Although a control strategy may include any number of responses, Table 4 identifies some elements that may be desirable to include in a control strategy that prioritizes buses. One issue for traffic engineers is the ability to provide bus priority in systems that are controlled by Urban Traffic Control (UTC) systems. Some bus priority systems can be very disruptive to normal traffic signal timing and phasing by "forcing" the traffic signal to a bus priority stage, which can disrupt normal traffic operations.

Several strategies can minimize the impact of signal priority on UTC signal systems. A bus signal priority system in use in London is designed so that when a phase of a traffic cycle is shortened or skipped to provide priority to a bus, on the following cycle, that phase is "reimbursed" for the time lost in the previous phase (Evans 1994). Alternatively, a signal system may be designed so that the signal returns to normal phasing as soon as possible, even if it means skipping a phase (Williams, Haselkorn, and Alalusi 1993). There are many different possible control strategies, and many different decisions that can go into determining the most appropriate control strategy for a given situation. Individual systems and intersections should be engineered to optimize a particular strategy given the intersection's role in the system.

Interagency Cooperation and Implementation of Signal Priority. Transit agencies and traffic engineers should cooperate to determine the optimal control strategy. Elements of various signal control strategies are enumerated in Table 4. Issues to be addressed include the desirability of skipping signal phases periodically or the amount of time allowable for a traffic signal to return to normal phasing after bus prioritization (PBQD 1994).

The tradeoffs associated with the many available vehicle detection technologies (Table 5) must also be considered. In the Puget Sound area, for example, many buses travel through multiple jurisdictions. Aware of the value of coordination, the region is in the process of selecting a single AVI technology for signal prioritization so that prospective signal priority systems will be compatible (Bevington and Jacobson 1994). A steering committee comprising representatives of transit agencies and

Table 4. *Elements of Signal Priority Control Systems*

	Element	Examples of Possible Strategies
Highly Desirable	Pedestrian clearance interval	Allow pedestrian interval and clearance intervals to expire before changing phase
	Conflicts with emergency vehicles	Allow emergency vehicles to override bus priority request
	Minimum green interval of current phase	Allow minimum green interval to clear for phase in operation before changing phase to favor bus
	Yellow change interval and all-red clearance interval	Allow yellow change interval and all-red clearance intervals to clear before changing signal to green for bus
Optional	Selective response to buses	Provide priority only to buses running behind schedule
	Frequency of response to bus priority calls	Once a bus has received priority treatment, will not provide priority treatment to other buses until one full cycle has elapsed
	Length of time to hold green light for bus	Will not extend green for buses beyond maximum green interval allocated to that phase
	Effect of signal priority on signal coordination	After bus priority call handled, traffic signal returns to its coordination scheme within 30 seconds, even if signal must skip a phase

Source: Adapted from Williams et al. (1993)

Table 5. *Advantages and Disadvantages of Various Vehicle Detection Technologies*

Technology	Suppliers	Features	Advantages	Disadvantages
Low Frequency RF (100-150 KHz)	MFS; Detector Systems/LOOPCOM; Vapor VECOM through Vapor; Vapor VECOM through LSTS	Uses inductive radio technology with transmitters on vehicle and standard loop detectors or antennas embedded in road; transmitters factory programmed or interfaced from onboard keypad	Transmitter are inexpensive and are easily removed or replaced	Message transmission may be hindered by accumulated dirt or snow on tag
Radio Frequency @ 900-1000 MHz	TOTE/ AMTECH; AT/ COMM	Uses transmitter tags mounted on side or vehicle top and antennas mounted roadside or overhead; historically used in toll collection, rail car, and containerized cargo ID; requires FCC registration	Transmitters are inexpensive and are easily removed or replaced; can transmit much information	Message transmission may be hindered by accumulated dirt or snow on tag
Spread Spectrum Radio	Automatic Eagle Signal/ Tracker System; Econcile/ EMTRAC	Sweeps narrow band signal over broad part of frequency spectrum; uses transmitter with directional antenna, an electronic auto compass in each priority vehicle, and receiver with omnidirectional antenna at each intersection	Can transmit much information	Not as accurate in locating bus as other RF technologies; can be affected by weather; may be more expensive
Infrared	Siemens / HPW infrared	Uses signpost on side of road to pick up and read signal; most common AVI technology for European bus priority systems	Well-proven in Europe	Limited ability to provide precise vehicle information; limited amount can be transmitted from vehicle; requires line of sight
Video	Racal Communications video with ALPR software	Video camera equipped with Advanced License Plate Recognition Software		Requires line of sight
Optical	3M / Opticom	Uses light emitter attached to transit coach and different frequency than emergency vehicles which have high priority	Potential advantage if intersections are already equipped with Opticom emergency preemption equipment	Limited ability to provide precise vehicle information and transmit from vehicle; requires line of sight
Vehicle Tracking	IBM / Vista System; TDOA & FDOA Tracking	Uses time difference of arrival and frequency difference of arrival to locate and track radio frequency transmissions from vehicle emitter		Buildings may block signal; may not provide precise location information for signal priority treatment

Source: Parsons Brinckerhoff Quade & Douglas, Inc. (1994)

** The information presented here does not constitute an endorsement of any particular technology* affected jurisdictions decided that the following criteria should govern the selection of the particular AVI technology:

- The AVI system selected should be able to provide precise location information (within 25 ft) at the point of detection.
- The system should have the ability to provide unique identification information for each vehicle in the fleet which can be dynamically modified from the bus in order to provide run numbers and route numbers, which change daily. In addition, the flexibility to allow for the downloading of additional information from the vehicle, such as security messages, passenger load data and schedule information is highly desirable.
- The system should interact effectively with the wide variety of signal control equipment in use in Snohomish, King, and Pierce counties, and to be used by the four transit agencies in the region.
- System costs per intersection (including capital, operations and maintenance costs for equipping the vehicle fleet with transmitters and the total capital, operations and maintenance cost per intersection approach of antennas or receivers) should be low enough to ensure cost effectiveness for the entire system. (It is likely that the transmitter-to-receiver ratio would be about five to one). (Bevington and Jacobson 1994).

Technologies Used for Bus Signal Priority. Signal priority technologies, which rely on AVI technologies, are advancing rapidly. AVI technology enables a message transmitted by the vehicle to be read and then transmitted to the signal controller (PBQD 1994). The choice of a bus detection technology depends on many factors, including the ability of the AVI system to interact with the signal control equipment being used, the system cost per intersection, and the ability to provide precise location information. In addition, those selecting an AVI technology should consider the level of detail of information wanted from the system. Some bus detection technologies are only able to indicate to the signal controller that a bus has been detected. Other systems are able to indicate that a specific bus (bus number 115, for example) has been detected. Still other systems are able to indicate that a specific bus on a specific route and run (bus number 115 on route 36, run number 5, for example) has been detected (PBQD 1994).

Following are discussions of three signal priority systems: Opticom 500 Series, TOTE, and Loop Comm.

Opticom 500 Series. The Opticom 500 series (distributed by Safety Signal Systems, Inc.) is 3M's newest signal priority system. The updated version of the Opticom 500 system, now in use in Bremerton, Washington, is a visual optical system for transit priority. This system will be able to identify up to 10,000 vehicles, a significant increase over its predecessor. This will enable Opticom to function as an AVI system as well. Each emitter will have a different strobe rate, corresponding to a pre-assigned, three-digit code.

This system continues to support two levels of priority: high priority, for emergency vehicles; and low priority, for non-emergency vehicles. The Opticom 500 series features five classes of both high- and low-priority uses, and can identify up to 5,000 each of high-priority and low-priority vehicles (Williams, Haselkorn, and Alalusi 1993). Pierce Transit is currently conducting a bus priority demonstration using this technology (Funkhouser 1996).

Transit on Time Emitter (TOTE). TOTE, distributed by McCain Traffic Supply, transmits data via high frequency radio waves (900 to 1000 MHz). It includes AVI tags from Amtech Corporation, an antenna, an interface module, and software (fig. 17). The tags can store up to 20 programmed digits, allowing vehicle identification and route numbers to be coded into them. As a bus passes, an antenna interrogates the tag and receives the vehicle identification and route numbers. This information is used to determine whether the bus is ahead of or behind schedule. The system can be specially programmed to attempt to change the signal for late buses to help them return to schedule (Williams, Haselkorn, and Alalusi 1993).

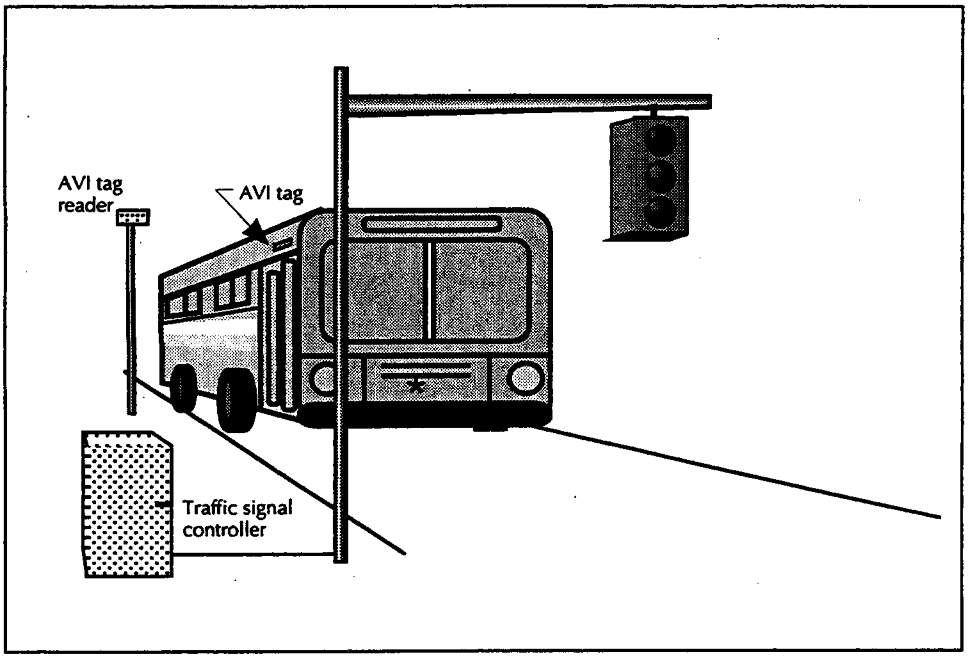


Figure 17. *Transit-on-time emitter (TOTE) Signal Priority System*

Loop Comm. Loop Comm, manufactured by Detector Systems, is based on inductive loop radio technology. Transmitters are located on the underside of buses, while the standard loop detectors are embedded in the roadway. Although most intersections are already fitted with loop detectors, existing loop detectors are often incorrectly located for signal priority (PBQD 1994). Part of Pierce Transit's bus priority demonstration, includes evaluation of the detection capabilities of CorpComm at several intersections (Funkhouser 1996).

Cost-effectiveness of Bus Signal Priority. Parsons Brinckerhoff Quade & Douglas, Inc. (PBQD) estimated the cost-effectiveness of bus signal priority in the Puget Sound Area with a computer simulation analysis (Table 6). Results of this analysis indicated that the travel time savings conferred by signal priority would be substantial enough to be cost-effective under many conditions (PBQD 1994). The simulation assumed the implementation cost of bus signal priority at $15,000 per intersection; HOV travel time savings were assigned a value of $7 per hour (calculated on a person-hour basis); a 30 percent reduction in delay at traffic signals; a project life of ten years; and, a real discount rate of 3.5 percent (PBQD 1993). These cost-effectiveness calculations were based on individual intersections. PBQD also simulated a system environment, including three consecutive intersections, to measure the impact on stops and delays. In this simulation, the results were less favorable: benefits to buses were inconsistent, and negative impacts on general purpose traffic were more frequent (PBQD 1993).

Additional General Suggestions for Designing Traffic Signals to Meet Transit Needs. Because most bus stops are located near intersections, many of which are signalized, traffic signals should accommodate buses and bus passengers. TTI (1990) suggests that the following guidelines be taken into consideration in designing signal systems:

- Bus stop locations should be coordinated with traffic signal pole and head locations. Bus stops should be located so that buses do not totally restrict the visibility of traffic signals for other vehicles (far-side stops, where feasible, prevent this problem).
- Because all bus passengers become pedestrians upon disembarking, WALK and DON'T WALK indicators are highly desirable at bus stops close to signalized intersections.
- Pedestrian push buttons should be installed to activate WALK and DON'T WALK indicators when traffic-actuated signals are installed.

Table 6. *Cost-Effectiveness of Bus Signal Priority at Given Levels of Service*

LOS B

Passengers	Buses per Hour: 2	4	6	8	10
10	0.1	0.2	0.2	0.3	0.4
20	0.1	0.3	0.4	0.5	0.7
30	0.2	0.4	0.6	0.7	1.0
40	0.3	0.5	0.8	1.0	1.3

LOS C

Passengers	Buses per Hour: 2	4	6	8	10
10	0.2	0.3	0.5	0.6	0.8
20	0.3	0.6	0.9	1.1	1.5
30	0.5	0.9	1.4	1.7	2.3
40	0.6	1.2	1.8	2.3	3.0

LOS D

Passengers	Buses per Hour: 2	4	6	8	10
10	0.2	0.4	0.7	0.8	1.0
20	0.4	0.8	1.3	1.6	2.1
30	0.6	1.3	1.9	2.4	3.2
40	0.8	1.7	2.5	3.2	4.2

LOS E

Passengers	Buses per Hour: 2	4	6	8	10
10	0.5	1.0	1.5	1.9	2.5
20	1.0	2.0	3.0	3.7	5.0
30	1.5	3.0	4.5	5.6	7.5
40	2.0	4.0	6.0	7.5	10.0

Source: *Parsons Brinckerhoff Quade & Douglas, Inc. (1993;1994)*

Notes: *a. Shaded areas indicate cost-effectiveness*

b. Assumptions:

- $15K per intersection used for implementation cost
- HOV travel time savings valued at $7 per hour
- 30 percent reduction in delay at traffc signals
- Project life is ten years
- Real discount rate at 3 percent

- Near-side stop areas often fall between the traffic signal's advance detectors and the crosswalk. Therefore, locating a detector at a bus stop will enable the bus to actuate the detector and the signal controller in order to obtain or extend the green light. When there is no detector, buses are forced to wait until other traffic coming from the same direction actuates the signal controller.
- Traffic signal timing should reflect buses' specific needs. Longer clearance intervals, for example, may be required on higher speed roadways with significant bus traffic. Vehicle passage times must provide adequate time for a bus to accelerate from the bus stop into the intersection. Intersections adjacent to railroad tracks should have timing and detection that reflect buses' need to stop at railroad crossings.

Some traffic signal designs that make sense for automobile traffic do not serve transit well. For example, for safety reasons, King County (formerly Seattle) Metro prohibits buses from turning right on red at most intersections. However, some jurisdictions design their traffic signals such that the signals do not respond to vehicles in the exclusive right-turn lane, with the underlying rationale that if only the traffic signal need not give a green light to a right-turning vehicle because the vehicles are assumed to turn right on red anyway. Metro buses must therefore wait until another vehicle arrives in the through lane to actuate the traffic signal (Stewart 1994). Enabling inductive loops for right-turn lanes on roads used by transit would address this problem.

Enforcement and Monitoring the Use of and Access to HOV Facilities

HOV enforcement has a direct bearing on a facility's success or failure (fig. 18). Inadequate enforcement tends to diminish public respect for the bus priority treatment, significantly reducing its effectiveness (Roark 1982). Table 7 summarizes enforcement strategies for the most common bus priority treatments. For a more complete discussion of enforcement strategies, see J. Roark's, *NCHRP Synthesis 2: Enforcement of Priority Treatment for Buses on Urban Streets*. Effective enforcement of HOV lane occupancy requirements (2+, 3+ or bus-only) may improve transit operations, since it reduces illegitimate use of the facility, thus decreasing delay to buses and other eligible vehicles.

Figure 18. *Enforcement of HOV lane occupancy requirements is critical*

Most enforcement technologies are based on automatic vehicle identification (AVI) technology. In Portland, Oregon, an operational test of AVI is underway to monitor access to HOV facilities. Registered carpools are issued vehicle ID cards, which are displayed in the windshield and read at the ramp. Buses are equipped with more permanent ID tags (Schweiger, Kihl, and Labell 1994).

TTI is also studying the application of advanced technologies including AVI, to automatic enforcement of HOV lane use. As in the Portland project, AVI technologies will identify eligible vehicles to a roadside reader. TTI is also investigating imaging technologies, which rely on video or other visualization techniques to distinguish individual vehicle passengers remotely (Schweiger, Kihl, and Labell 1994).

Engineers in Houston, Texas, are using AVI to monitor HOV lane performance, as opposed to monitoring enforcement. One thousand carpools have been equipped with AVI tags; these vehicles serve as congestion probes to record trip times on HOV lanes (Schweiger, Kihl, and Labell 1994). This information may then be used to evaluate HOV lane eligibility requirements. For instance, if the HOV lane were regularly experiencing congestion, authorities might raise eligibility from 2+ to 3+ to ensure that HOVs would still have reasonable travel time reductions.

Table 7. *Enforcement Strategies for Arterial HOV Treatments*

Treatment	Typical Violations	Enforcement Strategies
Median lane, concurrent flow	Unauthorized use of exclusive lane Illegal left turns across exclusive lane	Public education and heavy initial enforcement Identification and enforcement of upstream violators Use of closed left-turn bays for patrol-car observations as apprehension areas Transit marketing and good design for bus access to exclusive lane
Bus lane, curbside concurrent flow	Illegal parking and stopping in bus lane Unauthorized use of exclusive lane Illegal pedestrian maneuvers	Use of civilian agents or provision of police incentives Public education and posting of fines Heavy initial enforcement and towing of parked vehicles Passive enforcement and travel-time penalty Special enforcement on opposite curb lane Continuing enforcement
Median lane, contraflow	Unauthorized use of bus lane Illegal left turns and crossing of contraflow lane Inattentive crossing of contraflow lane by pedestrians	Design features for self-enforcement Adequate lane markings and signing Concentrated enforcement at intersections
Curb lane, contraflow	Illegal parking, stopping, or standing Illegal pedestrian and bicycle movements	Use of monitors for peak-hour enforcement Use of monitors for peak-hour enforcement, plus heavy fines and immediate towing to penalize violators
Bus-only streets	Unauthorized use of bus street Illegal crossing by pedestrians	Little enforcement required
Signal preemption	Transmitter held by unauthorized party Running of red light by motorists due to phase changes Running of red light by bus operator because of pre-anticipation of green phase	Routine traffic enforcement measures

Source: Adapted from Roark (1982)

The Georgia Institute of Technology hopes to conduct an operational test of advanced technologies for HOV lane monitoring. This project would test the use of prototype scanning radiometers to determine the number of people in a car by means of electromagnetic radiation, which records temperatures inside a car. Because humans raise the temperature of a car seat by about six degrees, this type of technology may be able to detect how many people are in the vehicle (Schweiger, Kihl, and Labell 1994).

Another system that monitors HOV lane performance is Traffic Reporter, a real-time traveler information system developed at the University of Washington (Haselkorn 1994). In addition to reporting real-time traffic speeds on freeways in the Seattle area, Traffic Reporter also separates out HOV lanes and compares speeds and travel times on HOV lanes to those on general purpose lanes. Thus, Traffic Reporter can tell users how much time they would have saved had they taken the HOV lanes instead of general purpose lanes. This type of system can help promote the travel time advantages afforded by HOV lanes, and can also help monitor travel times on these lanes to ensure that they are not becoming overly congested.

ADDITIONAL STRATEGIES

Exemptions from Turning Restrictions. Another way to provide an advantage to buses is to permit them to make turns that other vehicles may not make (fig. 19). Turn restrictions are sometimes used on arterials where the road is too narrow for an additional through or turning lane, or where turn restrictions may increase roadway capacity (AASHTO 1992). These turn restrictions sometimes disrupt bus route patterns, which can increase their travel distance.

Exempting buses from turning restrictions allows transit operators to follow the most efficient route and gives HOVs an advantage where congestion is a concern. The drawback is that exempting buses from turning restrictions can increase delay for other vehicles when buses are stopped while they wait for traffic to clear before making a turn. However, this delay to other roadway users may be offset by the time savings experienced by bus passengers (AASHTO 1992). This exemption can be communicated with signs or, in some cases, special traffic signals (Metro 1985).

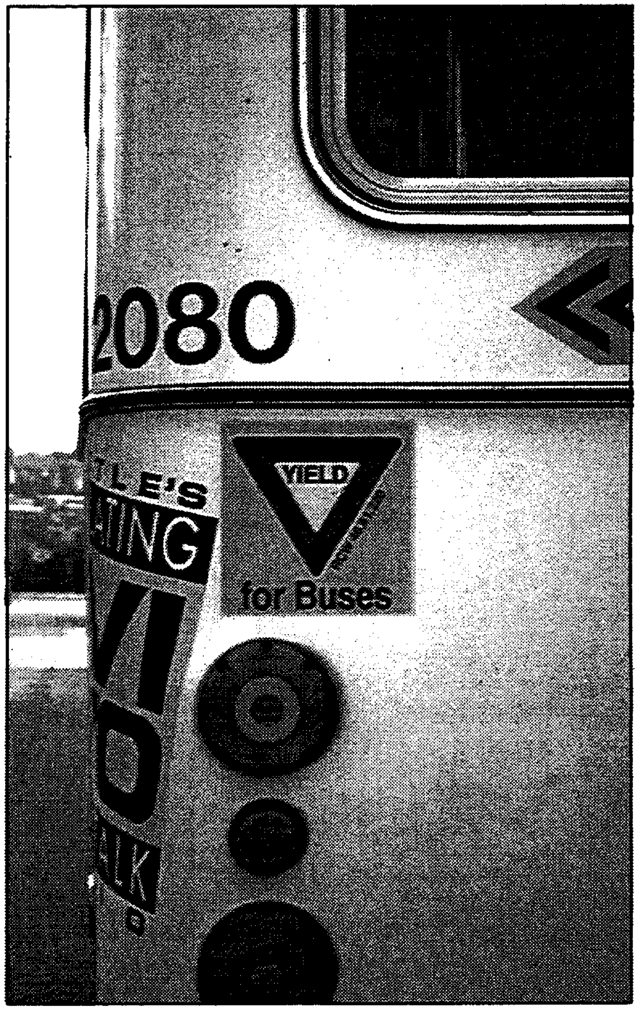


Figure 19. *Some jurisdictions have passed laws that require motorists to yield to buses*

Giving Buses Right-of-Way When Re-entering Traffic Stream. In response to the problems buses encounter as they attempt to re-enter the traffic stream after boarding passengers, some jurisdictions, such as Washington State and the province of Quebec, have passed laws that require automobiles to yield to buses in merge situations (McCormick Rankin 1994).

Signing and marking HOV facilities. HOV lanes or bus-only lanes must be visibly separated from general purpose lanes. The table on the following page provides guidelines for signing and marking HOV facilities. It should be noted that some conditions may warrant additional marking. In general, overhead signs are more visible than roadway signs. Where it is particularly difficult to distinguish the HOV facility from the general purpose lanes, overhead signs may be necessary. In areas with significant snowfall, overhead signs may be the major source of information to motorists (McCormick Rankin 1994).

Access Control on Arterial HOV Facilities. A safety hazard may arise when an automobile makes a left turn across an HOV lane to enter a driveway. If general traffic lanes are congested, then automobiles turning left may be unable to see faster-moving vehicles in the HOV lane. This is one reason that AASHTO recommends that speed differentials between concurrent flow HOV lanes and mixed-use traffic lanes in the same direction not exceed 10 to 15 miles per hour (1992).

Most arterial HOV lanes are used exclusively by transit vehicles. Arterial HOV lanes are often unable to serve carpools effectively because local buses must stop frequently to board passengers. Under the following conditions, both transit vehicles and carpools appear to be able to coexist relatively easily on HOV lanes:

- Where the primary HOV lane users are express buses that make limited stops
- Where HOV lanes are either wide enough (approximately 20 ft) to allow passing or include two HOV lanes
- Where bus turnouts are used, so that local buses do not delay express buses or carpools

PHYSICAL CHARACTERISTICS OF ARTERIAL HOV LANES

Lanes

A study by the National Cooperative Highway Research Program (NCHRP) reports that urban traffic engineers widely regard lane widths as narrow as ten ft as acceptable for urban arterial street improvement projects, and further, that lane widths under 11 ft can in many cases improve traffic operations and safety (Harwood 1990). Unfortunately, this study did not discuss the impact of narrow lanes on transit operations in depth.

Recommendations on minimum lane width for bus use vary. Levinson, for example, recommends a ten foot minimum, but concedes that in very unusual circumstances, a lane as narrow as 9 ft across may be acceptable (Levinson, Adams, and Hoey 1975). Other sources (Metro 1991; MTDB 1993) recommend minimum lane widths of 12 ft (for curbside lanes). Most transit agencies recommend lane widths of at least 11 ft (Table 8).

Although the "standard" 40-ft bus is 8.5 ft wide (AASHTO 1990), the inclusion of mirrors in the measurement puts the true width at 10.3 ft to 10.5 ft (Metro 1991; Municipality of Anchorage Transit Department 1993; TTI 1990). The implication of this more accurate measurement is that lanes narrower than 11 ft may be hazardous for transit use.

Turning radii/turning movements. The corner curb radius is a common design issue for buses (TTI 1990). The advantages of a properly designed curb radius have been identified as follow:

- Less bus/auto conflict at heavily used intersections
- Higher bus operating speeds and reduced travel time
- Improved passenger comfort

The following were also identified as factors to consider in designing intersection radii:

- Design vehicle characteristics
- Width and number of lanes on the intersecting street
- Allowable bus encroachment into other traffic lanes
- Bus turning radius
- On-street parking
- Right of way/building restrictions
- Angle of intersection
- Operating speed and speed reductions
- Pedestrians

Recommendations for bus turning radii (Table 9) range from an inside radius of 24.4 ft (AASHTO 1990) to 40 ft (Metro 1991) and an outside radius of 42 ft

Table 8. *Recommended Arterial Bus and HOV Lane Widths*

Source	Curbside	Median	Contraflow
	Arterial Bus/HOV Lane Type		
American Association of State Highway and Transportation Officials, Guide for Design of High Occupancy Vehicle Facilities (1992)	11 ft min [a] 12 ft pref [b]	11 ft min 12 ft pref	11 ft min 12 ft pref
Capital Metro Transportation Authority, Transit Facility Design Guidelines (1988)	11 ft min 12 ft pref	11 ft min 12 ft pref	11 ft min 12 ft pref
Giannopoulos, Bus Planning and Operation in Urban Areas: A Practical Guide (1989)	8.9 - 11.5 ft	8.9 - 11.5 ft	8.9 - 11.5 ft wide 13.1 ft max
Levinson, Bus Use of Highways (1975)	10 ft min 9 ft [c]	10 ft min 9 ft [c]	10 ft min 12 ft pref
McCormick Rankin, Operational Design Guidelines for High-Occupancy Vehicle Lanes on Arterial Roadways (1994)	11.5 ft min 12.3 ft pref	11.5 ft min 12.3 ft pref	11.5 ft min 12.3 ft pref
Metropolitan Transit Commission, Guidelines for Design of Transit Related Roadway Improvements (1983)	10 ft min 12 ft pref	10 ft min 12 ft pref	10 ft min 12 ft pref
Metropolitan Transit Development Board, Designing for Transit (1993)	12 ft min 14 ft pref	11 ft min 12 ft pref	12 ft min 14 ft pref
Metro Transportation Facilities Design Guidelines (1985)	12 ft	12 ft	12 ft
Parsons Brinkerhoff Quade & Douglas, Arterial High-Occupancy Vehicle Study (1991)[e]	10 ft min	10 ft min	10 ft min
Roark, Enforcement of Priority Treatment for Buses on Urban Arterials (1982)	11 ft min 12 ft pref	12 ft	11 ft min 20 ft pref
Texas Transportation Institute, Guidelines for Planning, Designing , and Operating Bus-related Street Improvements (1990)	11 ft min 14 ft. pref [g]	11 ft min 14 ft. pref [f]	N/A
Vuchic, Urban Public Transportation (1981)	11.5 ft	11.5 ft	13.1 ft

Notes:
a. Minimum; preferable
b. 13 to 14 ft with heavy pedestrian movement
c. In unusual circumstances
d. Refers to AASHTO desired width 12 ft
e. To allow buses to pass
f. 12 ft minimum on arterials

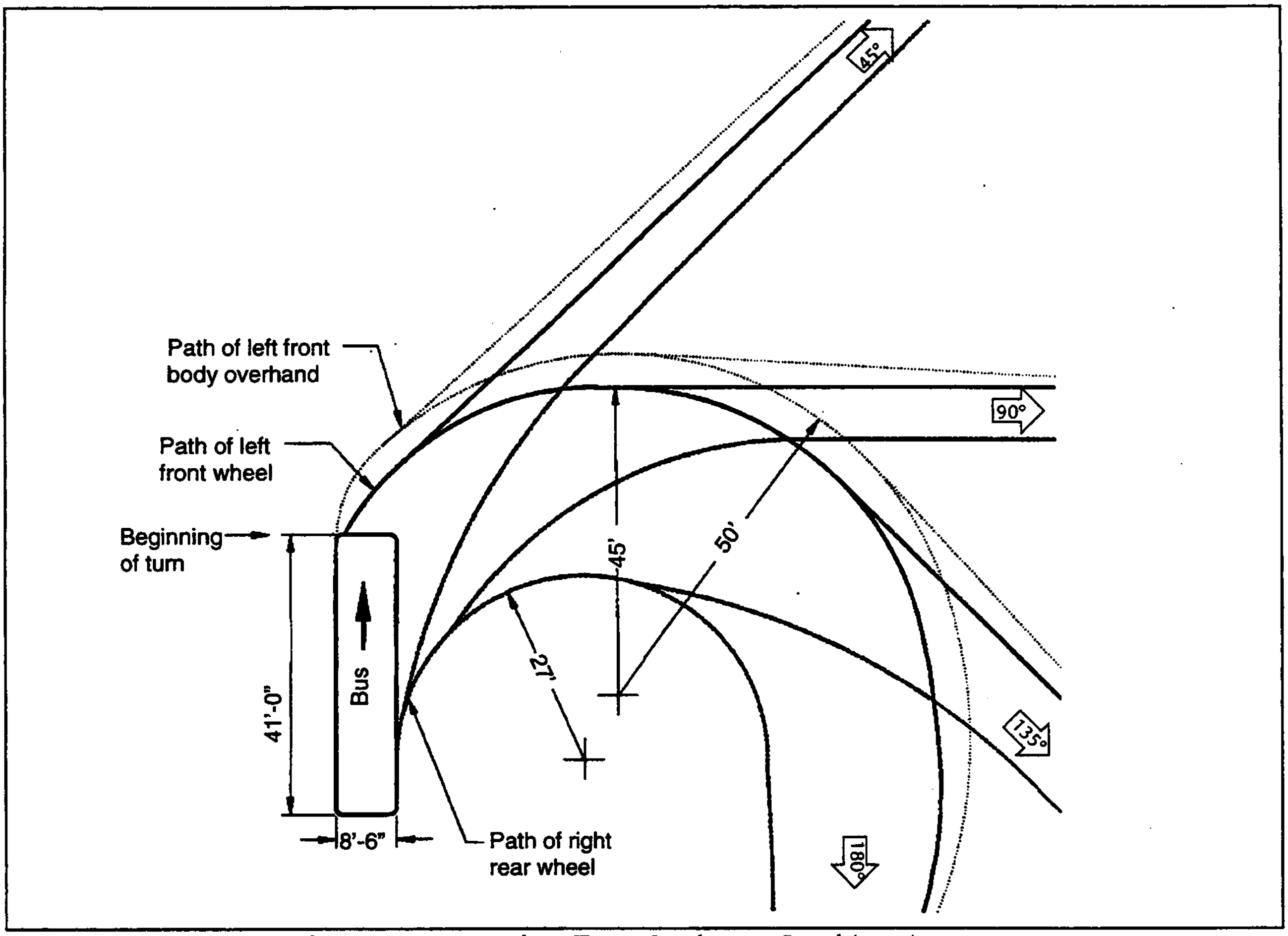


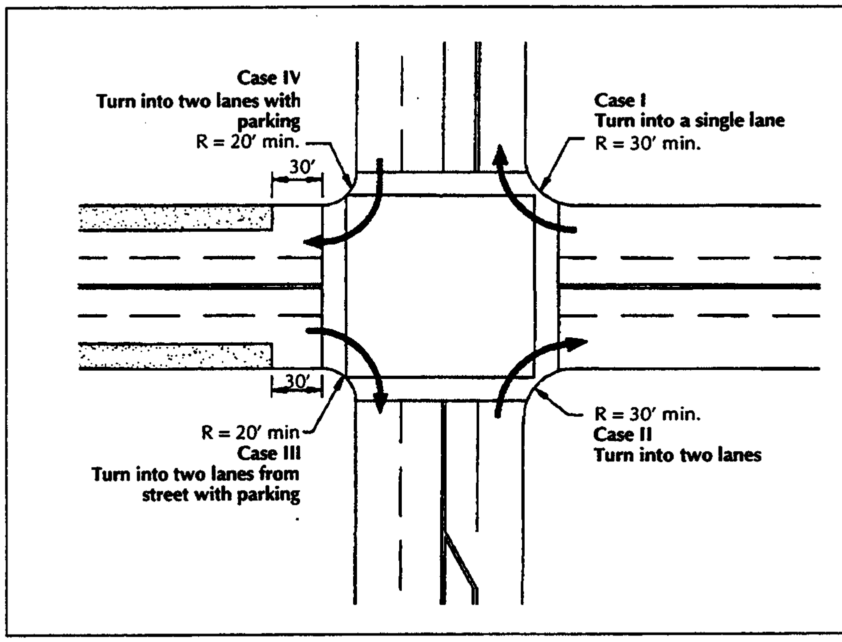
Figure 20. *Bus Turning Template. Source: Metropolitan Transit Development Board (1993)*

Table 9. *Recommendations for Bus Turning Radii*

Source	Turning Radii (in feet) Outside Radius	Inside Radius (curb)
American Association of State Highway and Transportation Officials (1990)	42	24.4
Metropolitan Transit Commission (1983)	47*	30
Metropolitan Transit Development Board (1993)	50	27
Orange County Transit District (1987)	50	N/A
Seattle Metro (1991)	N/A	40

* *Does not include overhang*

Figure 21. *Intersection design for bus turns*
Source: Metropolitan Transit Development Board (1993)



(AASHTO 1990) to 50 ft (MTDB 1993, Orange County Transit District 1987). The minimum radius recommended by AASHTO is based on speeds below 10 mph.

Wider turning radii allow buses to make turns more easily, and without encroaching into traffic in oncoming lanes. More generous turning radii may also allow buses to maintain speeds of over 10 mph during turning movements. Seattle Metro for example, recommends an inside turning radius of 40 ft to allow for comfortable street speed operation for its 35-ft, 40-ft, and 60-ft buses. Anything less requires that buses occupy two lanes while entering and leaving such turns (Metro 1991). Figures 20 and 21 provide two methods of calculating radii to account for bus turning movements.

The turning radius may also include a parking lane so that the net effective turning radius remains adequate for transit. Taking parking and shoulder width into account is the basis of another approach to determining corner outside radii.

One drawback of wider turning radii is that they may increase street-crossing distances for pedestrians. Increased vehicle speeds around these wider corners can be a serious safety problem. It is sometimes feasible to address this problem by building safety islands on particularly wide streets or on streets with heavy pedestrian or bicycle volumes.

Clearances. *Vertical*—MTDB recommends a minimum vertical clearance of 14.5 ft between the roadway surface and any overhead obstruction, such as trees or signs (MTDB 1993).

Horizontal—MTDB (1993) and Seattle's Metro (1991) recommend a minimum horizontal clearance of 2 ft between the edge of the curb and a lateral obstruction, such as a stop sign (fig. 22).

Grade. When building a new roadway, determination of roadway grade involves a compromise between safety and capital cost. The maximum grade for 40-ft buses is typically 6 percent to 8 percent (TTI 1990). TTI recommendations on maximum grades for 40-ft buses are shown in the table below. Ideally, grades for buses would be even lower. Seattle's Metro (1991), for example, notes that grades steeper than 3 or 4 percent severely reduce bus speed (for loaded buses). Grade-related slowdowns may adversely affect carpool operation on mixed-use HOV facilities (Table 10).

Table 10. *Recommended Maximum Grade for Buses*

Roadway Classification	Maximum Grade
Local	8%
Collector	7%
Arterial	6%

Source: Texas Transportation Institute (1990)

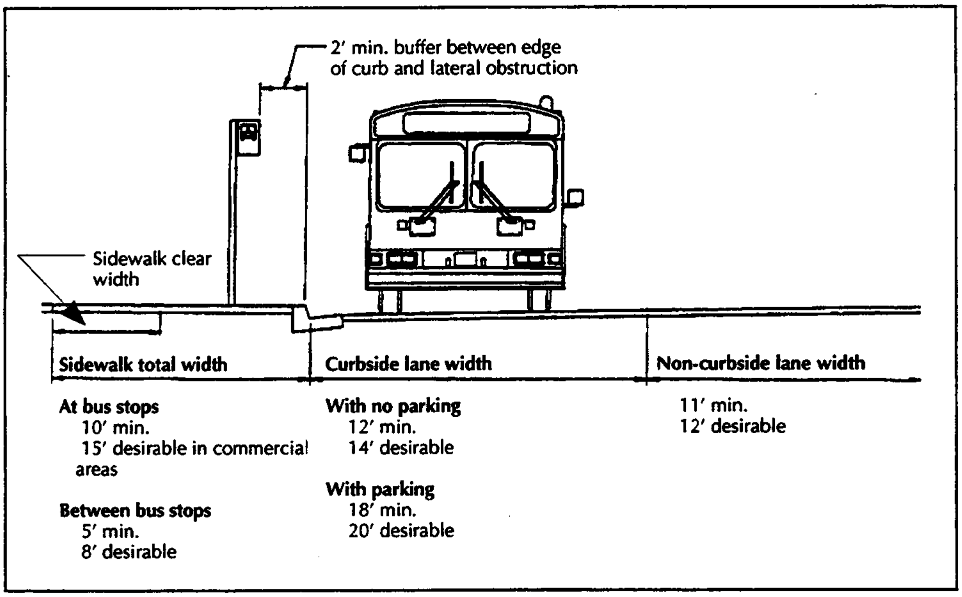


Figure 22. *Recommended vertical and horizontal clearances. Source: Metropolitan Transit Development Board (1993)*

BUS STOPS

Because picking up and dropping off passengers is a major source of delay for buses, the location and design of bus stops on arterials play an important role in transit operating efficiency (Vuchic 1981). Planning bus stops on arterials with HOV or bus-only lanes requires consideration of many of the same factors as required when planning bus stops on general purpose lanes, including location, spacing, and design.

Location. In relation to intersections, bus stops may be located near-side, far-side, or mid-block. Near-side bus stops are located immediately before an intersection; far-side bus stops are located immediately after an intersection; and mid-block bus stops are located in the middle of a block. Optimal bus stop location on bus-only or HOV lanes depends, of course, on the characteristics of the particular intersection. Once again, however, safety concerns dictate consideration of the particular aspects of each intersection on a case-by-case basis when locating a bus stop. Some transit agencies prefer far-side stops wherever possible (Stewart 1994), while others prefer near-side stops especially at stop-sign controlled intersections, where this placement reduces the number of stops a bus must make, as shown in figure 23 (Watry 1994).

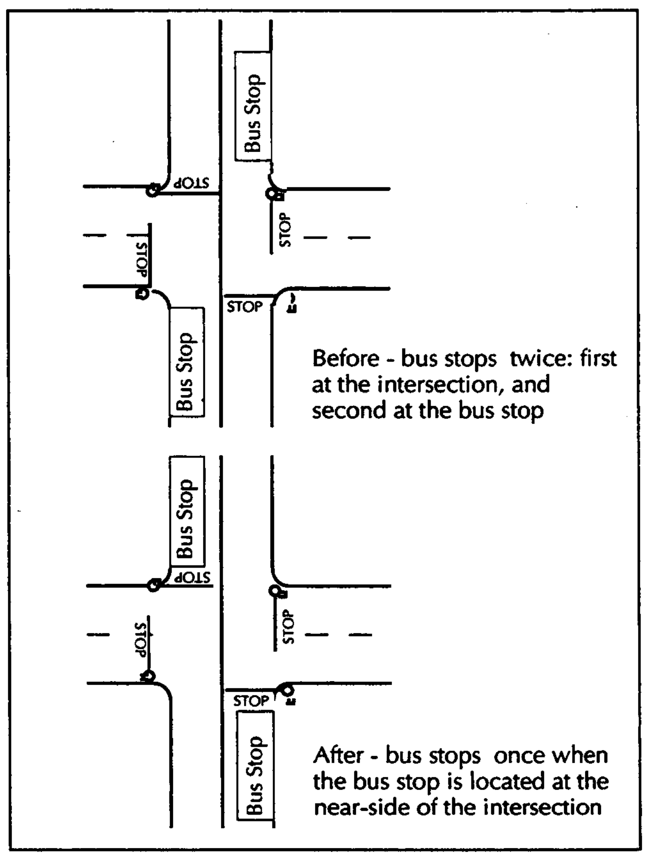


Figure 23. *Bus stop/stop sign coordination. Source: City and County of San Francisco (1989)*

Table 11. *Advantages and Disadvantages of Bus Stop Locations Relative to Intersection*

	Near-side	Far-side	Mid-block
Advantages	Buses will not need to stop again after going through intersection (note that bus might have to stop if station is too far back) Buses stopping just before intersection are traveling slowly, thus reducing the collision hazard Less interference with traffic turning into bus-route street from side street	Buses experience less delay when signal system is timed such that buses normally arrive at intersection on green, or where bus signal priority is used At signalized intersections, buses can find a gap to re-enter traffic stream easily (unless there are heavy turning movements into the bus-route street) Encourages pedestrian to cross at rear of bus Passengers encouraged to leave by rear door since this location is closer to crosswalk (only if fares are collected when passengers board bus); reduces loading/unloading time by 30% to 38% Reduces conflict between right-turning and stopped buses Sight distance improved for pedestrians and motorists	Improves bus driver sight distance, reducing conflicts with vehicles anc pedestrians Passengers wait to board at less-crowded part of sidewalk
Disadvantages	If right-turning volumes are high on bus-route street, near-side stops may create backups Buses obscure stop signs, signals, and other traffic control devices Boarding passengers cross in front of bus Buses obscure sight distance of drivers entering bus-route street from right cross-street	If many vehicles turn from cross-street onto bus-route street, far-side stops may conflict with turns If the bus stop is not designed to accommodate more than one bus at a time, heavy bus volumes may obstruct cross-street. May promote jaywalking with greater potential for accidents Stop at a stop-sign controlled intersection would require bus to make two stops	Passengers must walk longer distance from cross-street to bus stop Since entering and leaving tapers are required, more curbside parking must be removed for bus zone May promote jaywalking, with greater potential for accidents

When choosing among near-side, far-side, and mid-block stops, many factors, including pedestrian safety, traffic flow impacts, convenience, and nearby property owners' concerns, must be taken into account (Table 11). Bus stops should be located to minimize safety hazards and to avoid interference with other vehicular and pedestrian traffic. For instance, if an arterial roadway includes a sharp right curve just before the intersection, then a far-side stop may be safer because such placement would give traffic more time to react to a stopped bus. On the other hand, if a major employment center had a driveway on the far side of an intersection, a near-side stop could spare buses some of the delay due to conflicts with vehicles entering and leaving the busy driveway. If a jurisdiction uses bus signal priority, far-side stops will usually reduce delay to buses. Of particular importance are interference with turning movements, the ability of the bus to re-enter the traffic stream, and visibility at pedestrian crossings (Vuchic 1981).

Bus travel movements and intersection geometry may also influence bus stop placement. At intersections where most buses turn left, the bus stop will normally

Table 11 (cont.)

	Near-side	Far-side	Mid-block
Recommended Conditions	Where traffic is heavier on the leaving side than on approaching side Where transit flows are heavy, but traffic and parking conditions are not critical Where cross-street is one-way, operating from right to left in relation to bus	Where traffic is heavier on approaching side than leaving side Where intersection has a high volume of right turns from bus-route street Where far-side stops remove buses from complicated activities at intersection Where buses typically make left turns at intersection Where cross-street is one-way, operating from left to right in relation to bus	Where buses make right turn and curb radius is less than 50 ft Where traffic or physical street characteristics prohibit a near- or far-side stop adjacent to intersection In CBDs where multiple routes require long loading areas Adjacent to major transit trip generators

Sources: *Canadian Urban Transit Association (1985)*
Seattle Metro (now King County Metro) (1991)
Metropolitan Transit Commission (1983)
Wolfgang S. Homburger (1982)
Parsons Brinckerhoff Quade & Douglas, Inc. (1991)

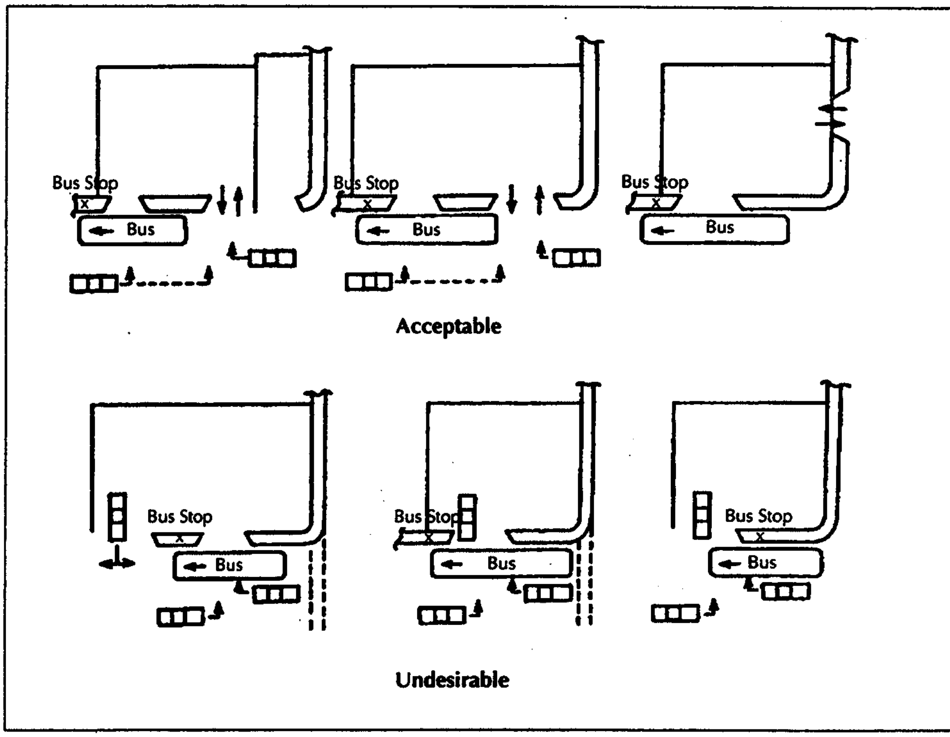
be far-side in the crossing street (Vuchic 1981). If the curb radius at an intersection where a bus makes a right turn is smaller than the minimum turning radius, a far-side stop may offer better geometry (Vuchic 1981). Table 10 enumerates some of the advantages, disadvantages, and conditions associated with various placements.

Relocation. A transit agency may wish to relocate a bus stop to improve operations. However, relocating bus stops is often problematic because of opposition from residents, transit passengers, or adjacent merchants. Relocation can also be costly. For instance, if existing curb lanes are not equipped with the proper pavement base to support bus operations, then the requisite bus pad construction may cost thousands of dollars, making it difficult to experiment with different bus stop locations (Skabardonis, Deakin, Harvey and Stevens 1990).

In some cases, transit agencies may want to relocate bus stops to improve operating efficiency. For example, when buses must stop at stop signs, and then again at far-side bus stops, they are essentially forced to make a "double stop" (City and County of San Francisco 1989). Where bus stops occur adjacent to stop signs on the near-side of an intersection, buses only need to make one stop (fig. 23). However, if the bus stop on the near-side were quite far back from the stop sign, then the bus would still have to stop at the intersection. "Double-stops" can slow service and make rides uncomfortable. S.F. Muni studied the impact of relocating a bus stop to the near-side of a stop-sign-controlled intersection at the intersection of Polk and Vallejo (1989). The average travel time for the bus decreased by 4.2 seconds (or 14 percent) at that intersection, while the average running speed increased by 1.3 mph (16 percent).

Nearby property owners may also wish to initiate bus stop relocation. Because of the expense and difficulty of moving bus stops, transit agencies sometimes adopt policies to discourage property owners from this tack. King County (formerly Seattle) Metro, for example, has a policy against moving a bus stop that is safely and efficiently meeting Metro's and a local jurisdiction's needs, a request by an adjacent property owner notwith-

Figure 24. *Acceptable and undesirable bus stop/driveway locations. Source: Texas Transportation Institute (1990)*



standing, unless specified criteria have been met (1991).

- The local jurisdiction must approve the relocation.
- An equal or better location that meets Metro's standards for safety, access, landing area, elderly and disabled access, and zone spacing must exist.
- The property owner requesting the move must secure initial permission from the new adjoining property owner.
- In the case of a bus zone with a shelter, the property owner requesting that the zone and shelter be moved must pay the cost of relocating the shelter.
- Exceptions to the policy are only considered in cases where multiple acts of vandalism can be documented.

Bus stop locations relative to driveways. Bus stop locations should not conflict with driveways. At least one driveway should be open to vehicles, as illustrated in fig. 24, which outlines acceptable and undesirable bus stop locations relative to driveways.

Traffic Signal Coordination

Traffic signal coordination can affect bus speeds on arterials. In the mid-1950s, Wolfgang von Stein developed and applied a simple rule, known as "von Stein's law of transit stop locations," noting that on a street with coordinated signals, alternate stops (e.g., near-side - far-side - near-side) result in the shortest delays (Vuchic 1981).

Bus Stop Spacing

Bus stop spacing is measured by the number of stops per mile of line, or the average distance in feet between stops. As bus stops are spaced at greater distances, buses stop less frequently, thereby reducing their travel time. However, spacing bus stops farther apart also requires that passengers walk farther to their stops. Bus stop spacing thus entails a compromise between bus delay and passenger convenience. Some cities are reevaluating their bus stop spacing in an effort to reduce bus travel times while maintaining the convenience for passengers (fig. 25). In San Francisco, for example, S.F. Muni reduced the number of bus stops on several streets and found that the average bus speed increased by 4.4 percent to

Table 12. *Recommended Bus Stop Frequency by Area and Route. Source: Levinson (1983)*

Route Type	Urban	Suburban	Rural
	Bus Stops per Mile		
Heavy	7 per mile	5 per mile	3 per mile
Medium	6 per mile	4 per mile	2 per mile
Light	5 per mile	3 per mile	2 per mile

Source: Levinson (1983)

14.6 percent (City and County of San Francisco 1989). However, removing existing bus stops can be difficult—transit riders who must walk farther to get to the next bus stop may exert considerable pressure on transit operators to keep existing stops in place.

One strategy in reducing the frequency of bus stops is to enhance the pedestrian environment. Although transit passengers may have to walk farther to reach their stops, the walk itself may be made more inviting and perhaps safer (Metro 1994b). Means of enhancing the pedestrian environment include upgrading landscaping, adding benches, and setting sidewalks farther back.

While bus stop spacing guidelines and policies must take land use, population density, and pedestrians into account, some general recommendations have been made with regard to frequency (Table 12). Levinson recommended that bus stop frequency not exceed eight to ten stops per mile (Levinson, Adams, and Hoey 1975). However, in dense urban areas, he recommended that buses stop on every block at least 500 ft long, and that buses stop on alternate blocks where the blocks are under 500 ft long.

More detailed bus stop spacing guidelines are available in Levinson's 1983 report. He found that during peak hours, local buses stopped at 68 percent to 78 percent of the designated stopping places, and that they stopped at as few as 30 percent of bus stops during off-peak hours. Levinson et al. (1983) recommended the following guidelines for the number of bus stops per mile by type of route and area.

Bus Stop Design

The most common bus stop designs are curbside bus stops and bus turnouts; less common designs include bus bulbs and boarding islands, (fig. 26), each of which is discussed herein.

Curbside Bus Stops. Curbside bus stops are the most common type of bus stop on arterials, regardless of whether those arterials feature special HOV facilities. Curbside bus stops may be located near-side, far-side, or mid-block. If an arterial includes both an HOV facility and a parking lane, then parking is normally prohibited throughout the length of the bus zone. Buses need adequate tapers so that they can safely drive into and exit from bus zones, allowing other buses or HOVs to pass the stopped bus while it boards passengers. Figure 27 provides design dimensions for a curbside far-side bus stop at a free-right-turn intersection; and fig. 28 provides design guidelines for curbside bus stops.

Curbside Bus Stops on Arterial Roadways Without Bus-Only or HOV Lanes. If the arterial does not have an HOV or bus-only lane, then the curbside lane,

Route Type	Orange County	Seattle	Portland	Toronto
	Bus Stops per Mile			
High Density	7	11	7	8
Low Density	4	4	5	5

Figure 25. *Bus stop spacing guidelines from selected North American cities*

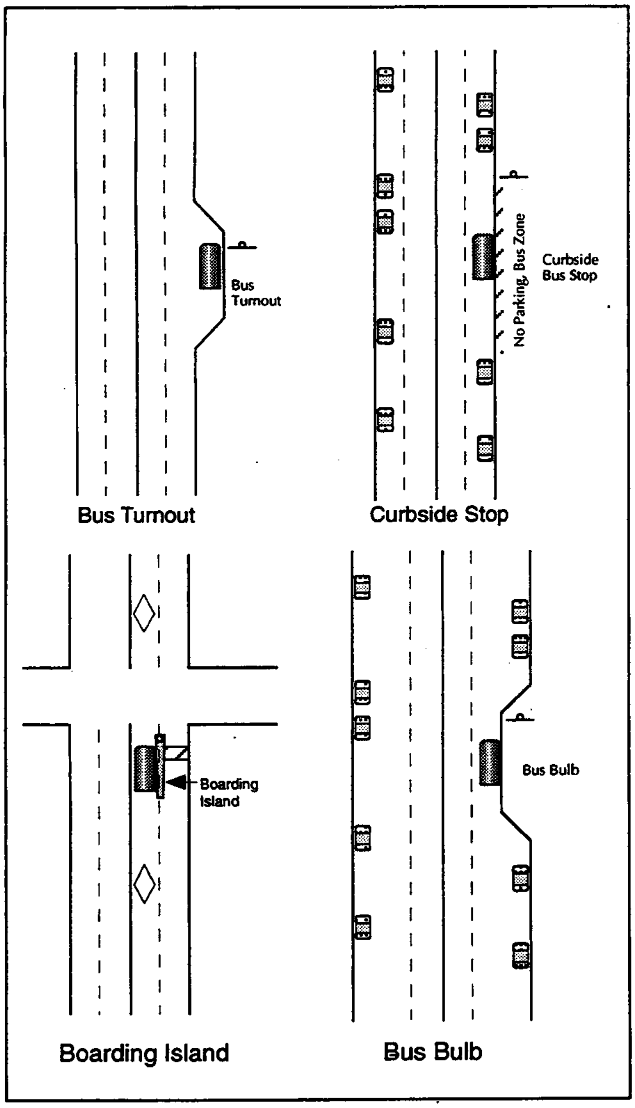


Figure 26. *Four bus stop types. From upper left (clockwise): bus turnout, curbside stop, bus bulb, and boarding island*

together with the parking lane, should be at least 20 ft wide if the goal is to have buses leave the traffic stream so that other vehicles can bypass stopped buses. Otherwise, a turnout may be necessary (Orange County Transit District 1987). Figure 29depicts design guidelines for bus stops in parking lanes or in extra-wide curb lanes.

Bus Turnouts

A bus turnout is a stop located in a recessed curb area (fig. 30). Separated from moving lanes of traffic, bus turnouts on arterials that feature bus-only or HOV lanes enable other HOVs to bypass buses that are boarding passengers. Where buses share the roadway with other vehicles, as on concurrent flow bus lanes, AASHTO suggests provision of bus turnouts to minimize conflicts among express buses, carpools, and local transit vehicles (1992). On contraflow lanes, AASHTO adds that bus turnouts should be used where bus volumes are high (over 100 buses per hour) since it is impossible for vehicles to bypass a stopped bus by changing lanes in contraflow situations.

For one-way, bus-only streets, AASHTO (1992) suggests that very high bus volumes (over 100 buses per hour) may warrant bus turnouts, and that the roadway should be 24 ft wide. For two-way bus-only streets, AASHTO (1992) suggests that very high bus volumes (greater than 100 buses per hour in either direction), may warrant bus turnouts, and that the roadway should be at least 40 ft wide.

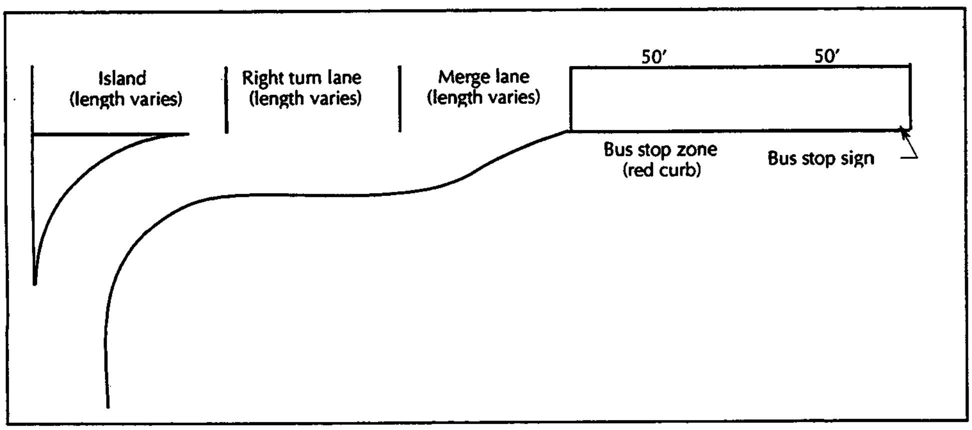


Figure 27. *Design dimensions for a curbside, far-side bus stop at a free-right turn intersection. Source: Orange County Transit District (1987).*

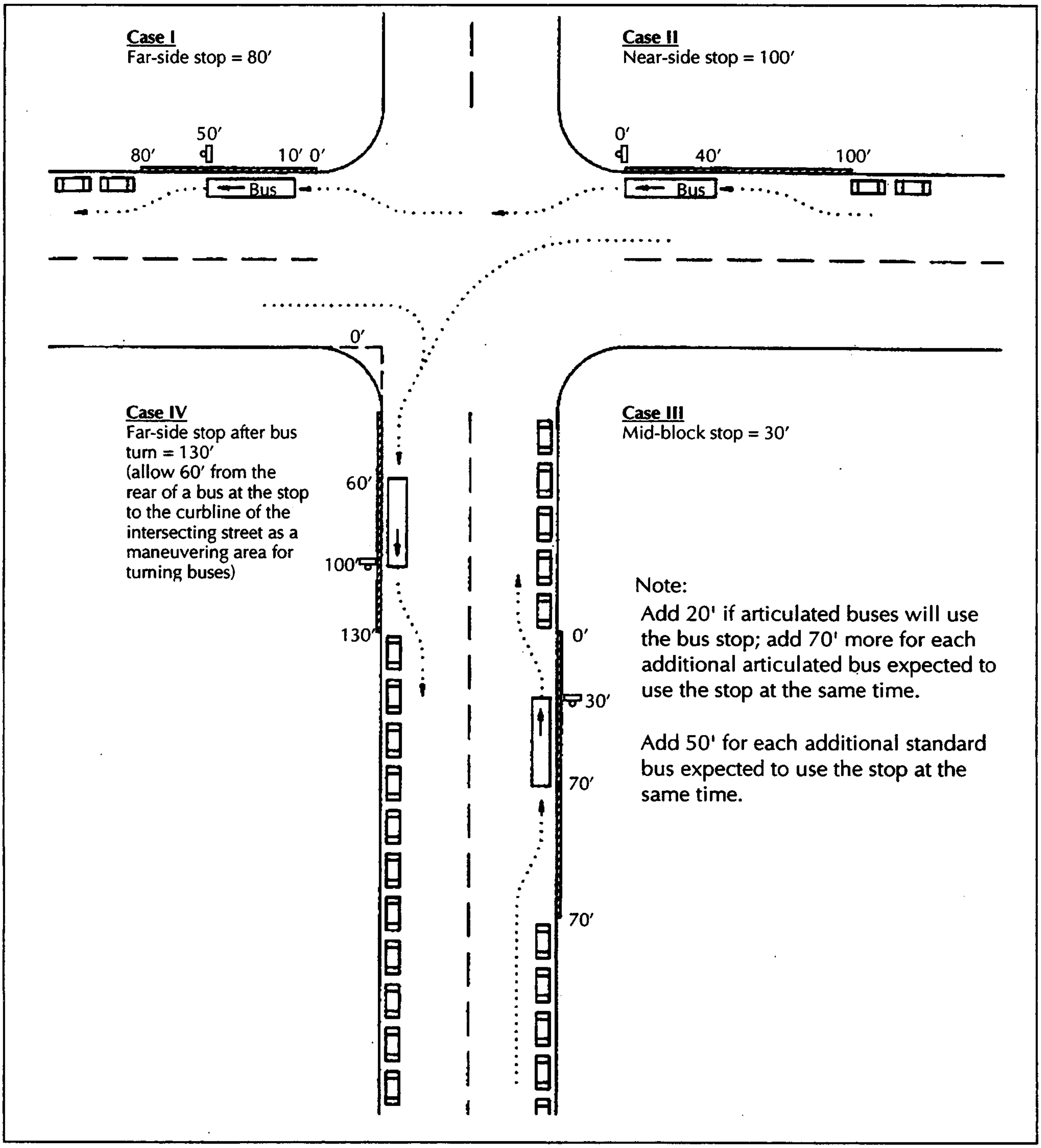


Figure 28. *Design features of curbside bus stops. Source: Metropolitan Transit Development Board (1993)*

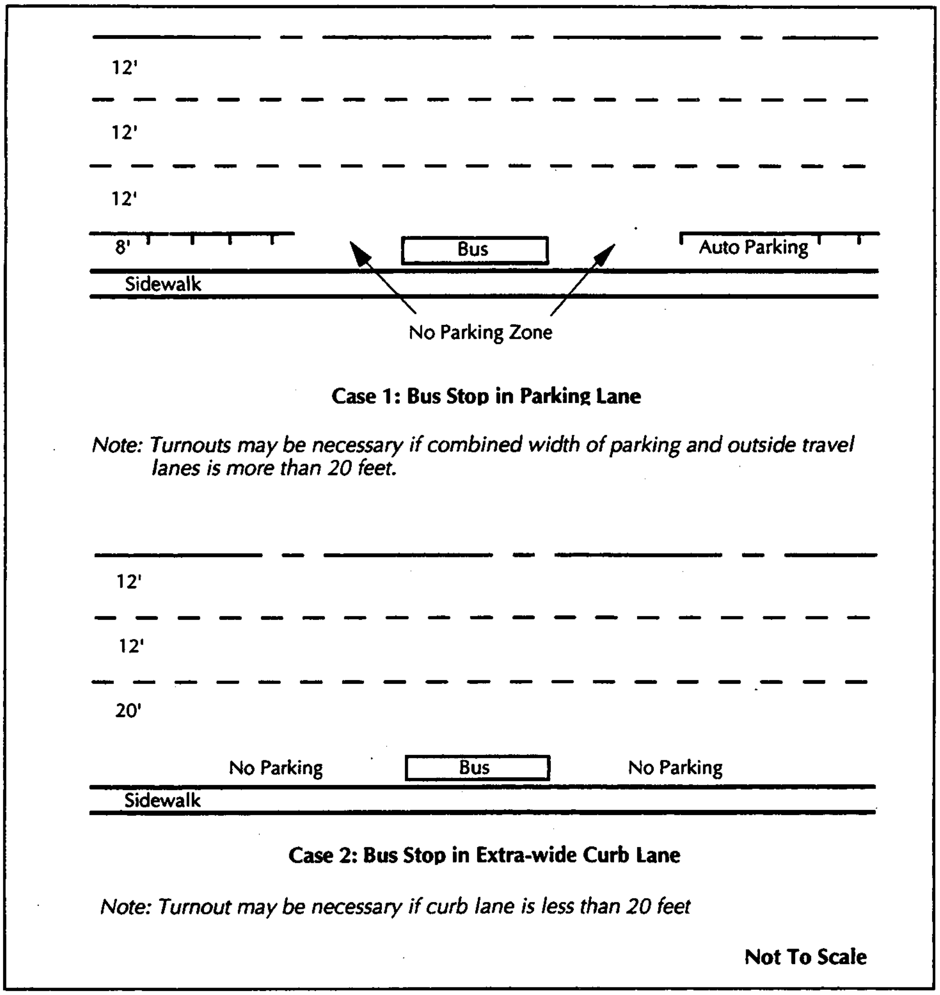


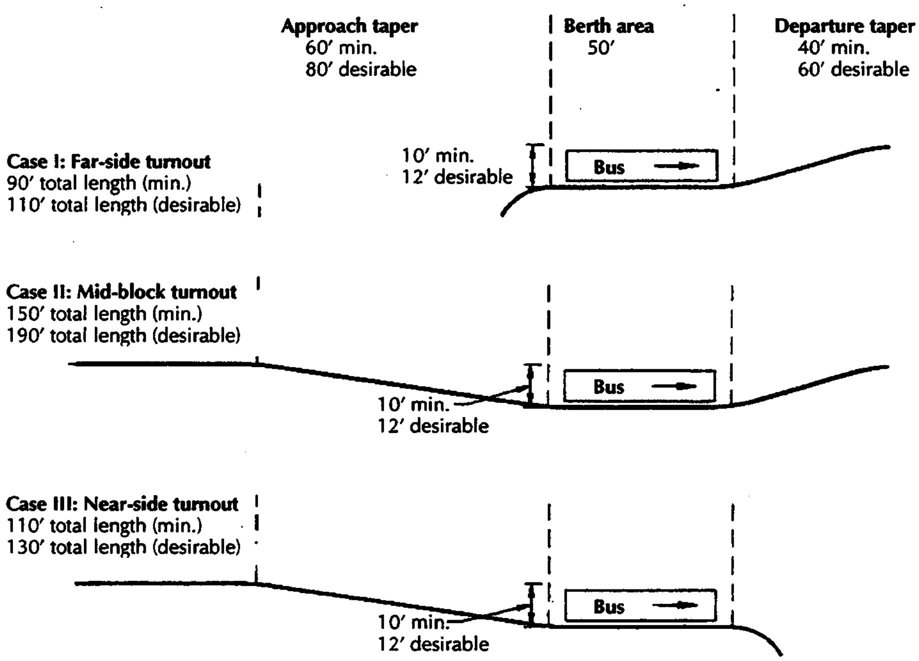
Figure 29. *Design guidelines for bus stops in parking lanes or in extra-wide curb lanes*
Source: Orange County Transit District (1987)

On HOV lanes where express buses and carpools also use the HOV lane, bus turnouts may be warranted for bus volumes under 100 buses per hour. Experience with bus turnouts on general purpose facilities suggests that bus turnouts on arterial roadways with bus or HOV lanes may also be warranted where bus dwell times are relatively long (adapted from Levinson, Adams, and Hoey 1975). Long dwell times may be routine at some bus stops, such as timed transfer points and route layovers (Tri-Met 1993), and at stops regularly serving disabled passengers.

Advantages. Because bus turnouts on arterial HOV lanes allow buses to board passengers outside the HOV lane traffic flow, bus turnouts smooth express bus operations on curbside HOV lanes. Bus turnouts may also make arterial HOV lanes more attractive to carpools by reducing delay to other HOVs on the roadway.

Disadvantages. The downside of bus turnouts is that they make it difficult for buses to reenter the traffic stream where volumes in the curbside HOV lane are high. Another disadvantage is that construction costs for bus turnouts are high compared to curbside bus stops.

Design. Where bus turnouts are necessary, far-side stops may facilitate bus reentry into the traffic stream since natural breaks in traffic occur in conjunction with signal changes (Metro 1994b). Where bus pullouts exist on the far side of an intersection, no approach tapers are necessary (Tri-Met 1993). Tri-Met suggests a minimum acceptable pullout width of 11 ft, although 12 ft is preferable on arterial streets with higher traffic speeds (Tri-Met 1993).

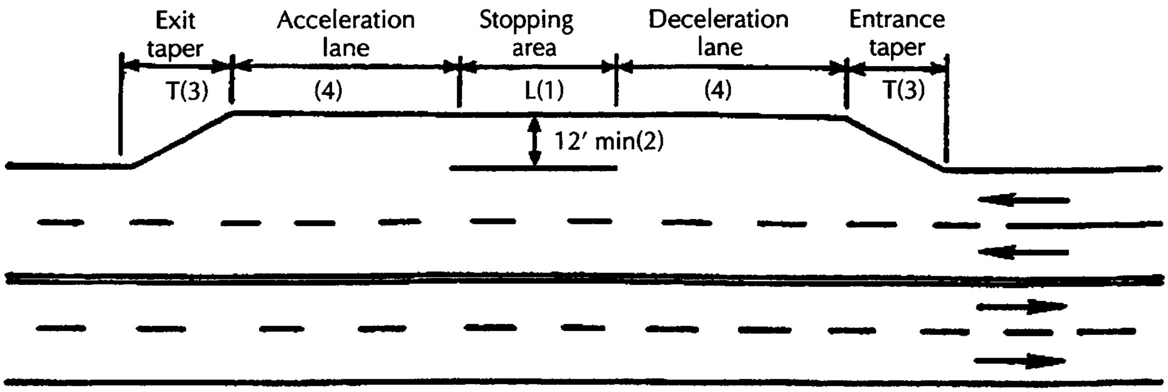


Approach Area Note: Dimensions of taper assume that buses will decelerate mostly in the approaching travel lane.

Berth Area Notes:
- Add 20' to length of berth area if articulated buses will use turnout; add 70' more for each additional articulated bus expected to use the turnout at the same time.
- Add 50' for each additional standard bus expected to use the turnout at the same time.

Departure Area Notes: Dimensions of taper assume that buses will accelerate mostly in the departing travel lane.

Figure 30. *Basic design parameters for bus turnouts. Source: Metropolitan Transit Development Board (1993)*



1. Stopping area length consists of 50 feet for each standard 40 foot bus and 70 feet for each 60-foot articulated bus expected to be at the stop simultaneously.
2. Does not include gutter width. For speeds under 30 mph, a 10-foot minimum may be used.
3. Recommended taper lengths are listed in the table below. Desirable taper length is equal to the major road through speed multiplied by the with of the turnout bay. The Green Book states a taper of 5:1 is a desirable minimum for an entrance taper to an arterial street bus turnout, while the merging or reentry taper should not be sharper than 3:1.
4. Minimum design for a bus turnout does not include acceleration or deceleration lanes. Recommended acceleration and deceleration length are listed in the table below (8).

Through Speed (mph)	Entering speed (mph)	Length of deceleration lane (feet)	Length of acceleration lane (feet)	Length of taper (feet)
35	25	184	250	170
40	30	265	400	190
45	35	360	700	210
50	40	470	975	230
55	45	595	1400	250
60	50	735	1900	270

Figure 31. *Design guidelines for bus turnouts with deceleration and acceleration tapers included. Source: Texas Transportation Institute (1991)*

Ideally, bus turnouts should be designed with entering and exiting tapers, deceleration and acceleration areas, and a stopping area (fig. 31). However, most minimum designs for bus turnouts do not include deceleration and acceleration areas (TTI 1990).

Bus bays are bus turnouts that are further separated from the traffic stream by an island or other physical separation. Bus bays and bus turnouts have much in common. While both provide greater passenger safety, both often require more right-of-way than do either curbside bus stops or bus turnouts (Giannopoulos 1989). Major transit transfer points, such as shopping centers, are the most likely candidates for bus bay installation. In areas with high transit demand where several bus routes converge, it may be necessary to build multiple berths in a single bus bay.

Bus Turnouts on Arterial Roadways Without Bus or HOV Lanes. Some transit agencies have suggested guidelines for bus turnouts on general purpose facilities. Authorities in Orange County, California, for instance, suggest that bus turnouts on general purpose facilities may be warranted if one or more of the following conditions exists:

- bus parking in the curb lane is prohibited
- traffic in the curb lane exceeds 250 vehicles during the peak hour
- passenger volumes exceed 20 boardings per hour
- traffic speed exceeds 45 miles per hour, or accidents are recurrent (Orange County Transit District 1987)

Seattle Metro suggests that bus turnouts on general purpose facilities may be warranted if one or more of the following conditions exist:

- The speed limit is 35 mph or above on a two-lane road or 40 mph on a four-lane road
- Sight distance is poor (on curve or crest of hill),
- Dwell times at the bus zone are long (over 30 seconds)
- The accident rate is high (rear-end collisions or sideswipes)
- The stop regularly serves disabled passengers or there is no area in which to board passengers safely (Metro 1991).

Bus Bulbs

Bus bulbs are stops that are designed specifically to prioritize buses over automobiles. Bus bulbs favor buses by allowing them to board passengers without ever leaving the traffic stream (fig. 32). This eliminates problems buses often encounter as they try to reenter the traffic stream after stopping. Bus bulbs are usually applicable on streets without bus-or HOV-only lanes. In constructing a bus bulb, the sidewalk is extended to the edge of the lane of travel, usually through the parking

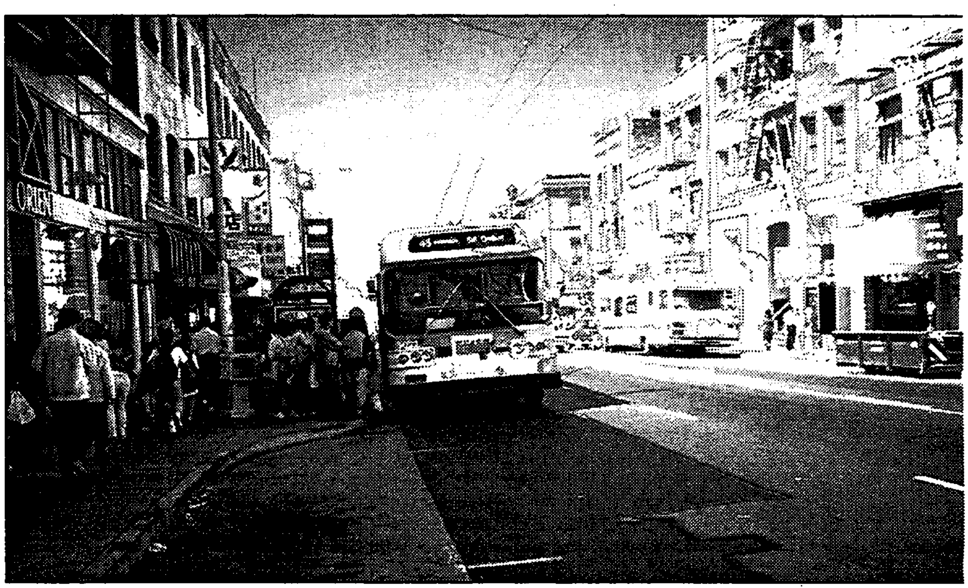


Figure 32. *Bus bulb in San Francisco*

Figure 33. *Boarding island in San Francisco*

lane. Automobiles thus are forced to wait behind the bus as it boards passengers.

Advantages. One advantage of bus bulbs is that they may not require the removal of as much parking space as do curbside bus stops. While a mid-block, curbside bus stop generally requires the removal of up to 170 ft of parking space, a mid-block bus bulb may require just 85 ft. Because bus bulbs widen sidewalks, they constitute a pedestrian-oriented design that may support transit use. Near-side bus bulbs have an advantage insofar as they reduce the distance pedestrians must walk to cross at intersections.

Disadvantages. Because bus bulbs allow buses to stop in the traffic stream while boarding passengers, they delay vehicles traveling behind the bus. Therefore, bus bulbs are probably best suited for streets designated for transit priority. In addition, because the bus remains in the traffic lane while boarding passengers, bus bulbs should only be used where boarding is apt to be speedy. For example, bus bulbs are not advisable at stops that frequently serve passengers who need to be lifted onto the bus. Another drawback of bus bulbs is that if buses are running ahead of schedule, bus bulbs would be an inappropriate place to wait until the bus is back on schedule (because of the delay to other vehicles). Another possible drawback centers on other vehicles' attempts to bypass stopped buses by crossing into the oncoming traffic lane. It is not clear to what extent this occurs, or to what extent it constitutes a safety hazard.

Design issues. Ideally, a bus bulb should be long enough to board passengers from both the front and back of the bus. Another issue to consider in designing bus bulbs is their serviceability by street sweeping or snow removal equipment. Where bus bulbs are located on the same block on opposite sides of the street, it may be helpful to stagger their placement to avoid "pinching" the street off in the middle.

Boarding Islands

Boarding islands are passenger loading areas that may be constructed in median or center lane HOV facilities (fig. 33). Passenger loading areas located in a median or adjacent to a center lane must be designed for pedestrian safety and comfort.

Advantages. The advantage of boarding islands is that they allow both express and local buses to use the roadway's inside or median lanes. On the other hand, boarding islands have two chief drawbacks: (1) they require additional right-of-way; and (2) if they are not designed properly, they can be dangerous for pedestrians.

Design. While the length of a boarding island depends on the number of buses expected to use the loading area at a time, they should not generally be under 50 ft long, and they should be wide enough to provide for pedestrian storage and movement. In no case should the island be less than five ft wide. Where traffic flows on both sides of a passenger island, a 10-ft minimum width is recommended (AASHTO 1992).

Loading areas should be raised to allow passengers to board easily. To discourage jaywalking and to prevent pedestrians from inadvertently stepping out into traffic, side protection, such as splash plates, posts connected by chains, or mesh fencing, may be provided. Loading areas should always be contiguous to a marked crosswalk, and should include wheelchair ramps (AASHTO 1992).

Bus Stop Designs to Conform with the Americans with Disabilities Act

The Americans with Disabilities Act (effective 1992) mandates a more integrated approach to bus stop design (Tri-Met 1993). Title II, Part A, of the ADA indicates that local jurisdictions are responsible for making newly constructed sections of the common pathway accessible to all (fig. 34).

Landing pad. The ADA states that at locations where a wheelchair lift is deployed, suitable passenger loading pads, at least 8 ft by 5 ft in area, should be provided. The ADA pad description further requires a clear zone, an area unobstructed by trees, fire hydrants, buildings, or other features perpendicular to the roadway, with a grade no steeper than 2 percent (Tri-Met 1993).

Accessibility. The ADA requires that bus stops be connected to all streets, sidewalks, and/or trails within the site boundary by an a accessible route. The site boundary is defined by the beginning and end of the bus stop, the adjacent street, and the right-of way line for the street segment containing the bus stop. Where a bus stop serves as a transfer point, the site boundary and the accessible route are to extend to connecting route bus stops. Where a bus stop is the closest stop to an intersection, major generator, or other private development, it is necessary to extend both boundary and route to the generator or development. In the case of a mid-block stop with no adjacent sidewalk or trail, it is desirable to provide an accessible route to the nearest intersection or signal-protected crosswalk. However, if the distance to the nearest intersection or protected crosswalk is substantial (over 300 ft), and the project budget is insufficient to build the sidewalk or trail connection, any potential ADA- certified passengers with disabilities become eligible for complimentary paratransit service for trips that would require the use of the stop until the accessible pathway is provided (Municipality of Anchorage 1994).

Width of walks and ramps. Accessible routes should be at least 5 ft wide. A minimum width of 3 ft is legally acceptable as long as 5-ft by 5-ft passing spaces are provided at intervals of 200 ft or less.

Side and vertical clearances. Accessible routes must be completely clear of objects protruding from the surface or from the sides that would narrow the pathway (e.g., fire hydrants, parking meters, sign posts, benches, landscaping, etc.). A minimum clear head room of 80 in is to be maintained on accessible pathways.

Surfacing. Surfaces along accessible routes are to be stable, firm, and slip-resistant. It is recommended that routes be paved with either 4-in thick Portland Cement Concrete, or 1.5-in thick asphalt concrete pavement. An appropriate foundation is to be provided for surfacing.

Grades, changes in level, and cross-slopes. Any part of an accessible route with a slope steeper than five percent is considered a ramp and must conform with ramp specifications. Changes in level greater than 1/4 in are to be accommodated in accordance with standards applicable to ramps. The maximum cross-slop permissible is two percent.

Gratings. Gratings should not be placed in accessible routes. If grating must be located in the route, openings are to be no wider than 1/2 in one direction. If gratings have elongated openings, they are to be placed such that the long side is perpendicular to the direction of travel.

Ramps. Segments of accessible routes with grades steeper than five percent or changes in level greater than 1/4 inch are to be designed in accordance with the section. All other accessible route requirements are to be applied to ramps.

Grades. The maximum slope for any ramp segment is 8.3 percent. However, where site infeasibility precludes a slope of 8.3 percent, the least possible running slope is to be provided. The maximum rise for any segment of an accessible route with a grade greater than 5 percent is 30 in. A landing is to be constructed on the ramp after each 30 in of rise. The minimum landing size is specified as 5 ft by 5 ft.

Changes in level. Any change in level on a bus stop pad or accessible route greater than 1/4 in but less than 1/2 in must be leveled to a slope of no more than 1 in of rise per 2 in of run. For this reason, paving materials such as bricks or concrete blocks should be avoided in pad and pathway surfaces. Any change in level on a bus stop pad or accessible pathway greater than 1/2 in requires a ramp.

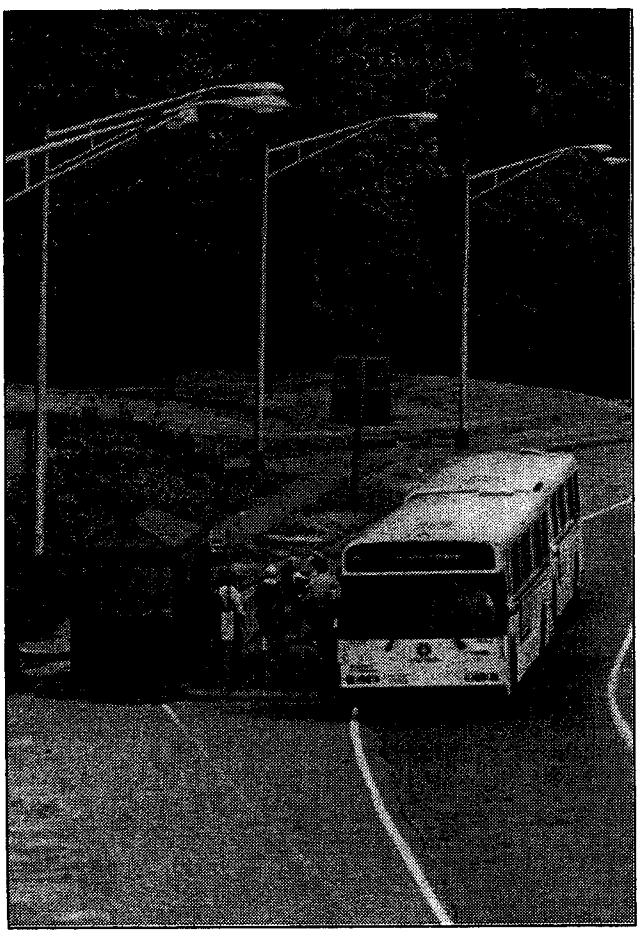


Figure 34. *Attention to accessibility is required by law.*

PART 2

FREEWAY HOV TREATMENTS

BASIC HOV LANE TYPES

The three basic types of freeway HOV lanes intended for shared use by both carpools and buses are physically separated HOV lanes, concurrent flow HOV lanes, and contraflow HOV lanes. In addition, roadway shoulders are sometimes converted to HOV use.

Separated HOV Lanes

Separated HOV lanes are isolated from adjacent traffic by physical barriers or ample striped buffer space. Separated HOV lanes are usually constructed in the freeway median, which allows for lane reversal to accommodate traffic in both peak directions. Wholly separate alignments may also be built, although their high cost is often prohibitive. Separated HOV lanes may be reversible or two-way (figs. 35 and 36). Reversible HOV lanes normally require a physical barrier to separate the HOV facility from the general purpose lanes. One drawback of reversible lanes is the high cost associated with the need for on- and off-ramps in both directions, physical barriers, and special safety provisions.

Physical barriers. Physical barriers (e.g., Jersey barriers) separate HOV and general purpose lanes most definitively. Beyond safety, another reason that this physical separation may be desirable is that it may indicate a more permanent commitment to the HOV concept, which may give commuters more confidence to shift to rideshare modes.

Maintaining a smooth flow dictates the need for a space or shoulder to allow for passing disabled vehicles. Thus, barrier-separated HOV lanes are usually constructed with at least two functional lanes. However, the need for shoulders alongside both HOV and general purpose lanes implies a wider roadway.

AASHTO (1992) specifies 12 ft as the minimum desirable lane width, although 11 ft may suffice where space is tight. If an 11-ft width is used, a two-ft offset to the barriers should be provided to avert accidents. For speeds exceeding 50 miles per hour, AASHTO notes that a more desirable alignment would include two 12-ft lanes with a 4-ft offset and a 10- to 12-ft shoulder to accommodate disabled vehicles.

Barrier-separated HOV facilities are usually configured for reversible access and flow to accommodate the greatest volumes in both peak directions. Two-way operations should include standard provisions for safety, including separation techniques and appropriate speed limits.

Buffer barriers. Using buffers for separation is more flexible than using barriers in that changing the lane to another use requires less effort and expense. Buffer separation is also advantageous in that it requires less right-of-way for the breakdown area for the general purpose lanes, and the buffer area between the general purpose lanes and the HOV lanes are combined. In addition, buffer areas give HOV lane drivers space in which to react to an encroaching vehicle from the general purpose lanes.

Because this section focuses on the needs of transit in facility design, the very general treatment of freeway HOV design issues is intended simply to provide a frame of reference for the discussion of transit-specific matters. Readers should see Charles Fuhs's work, *High Occupancy Vehicle Facilities: Current Planning, Operation, and Design Practices* (1990), for a thorough treatment of HOV facility design and operations

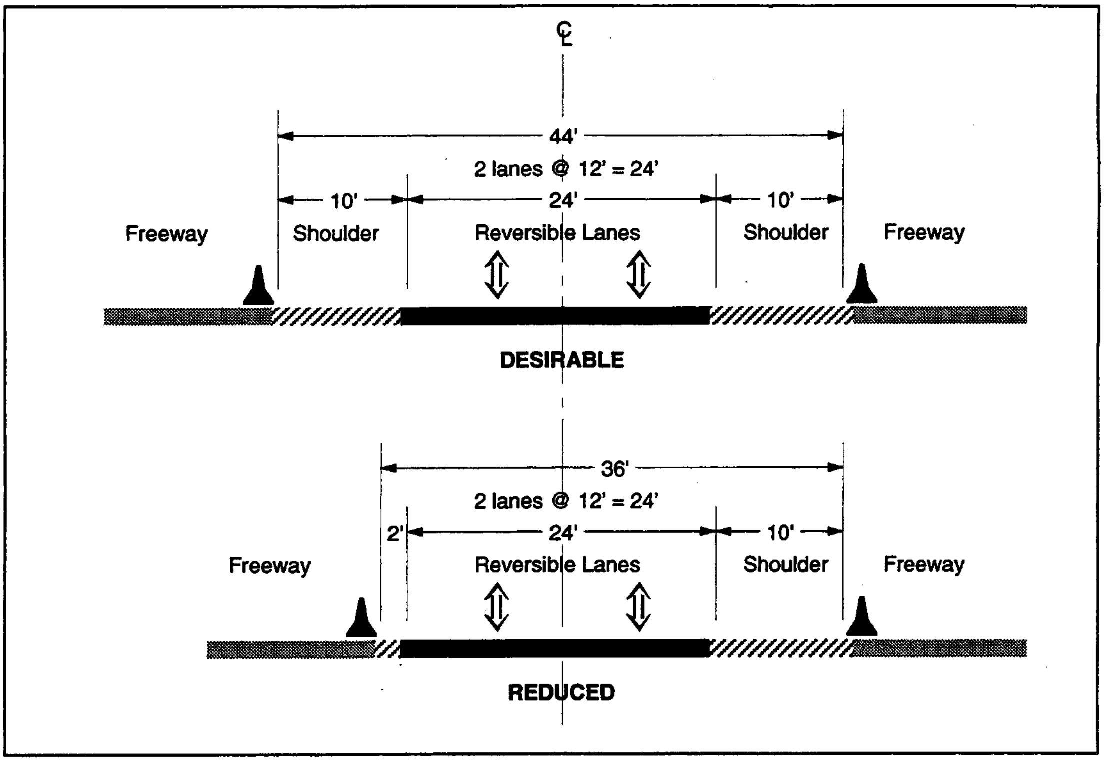


Fig. 35. *Recommended multiple-lane, reversible-flow cross-sections. Source: Fuhs (1990)*

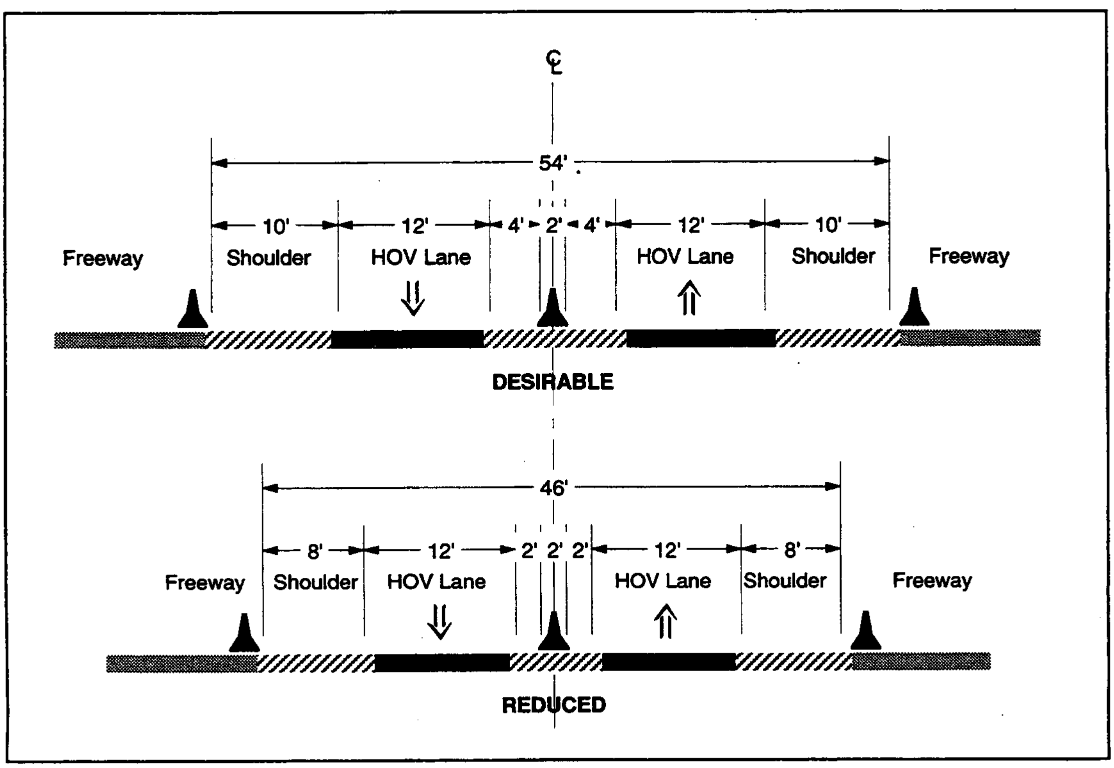


Fig 36. *Recommended two-way, barrier-separated cross-sections. Source: Fuhs (1990)*

Concurrent Flow HOV Lanes

Concurrent flow lanes (fig. 37), contiguous flow lanes, and non-separated flow lanes, are defined as roadways in the peak flow direction separated from adjacent traffic by a narrow buffer (usually less than 4 ft wide) or separated simply by distinctive pavement markings (Fuhs 1990; ITE 1991). Concurrent-flow lanes are usually located on the inside or median lane, outside locations are relatively uncommon.

Buffer-separated HOV lanes and concurrent flow HOV lanes are distinguished not only by buffer width, but also by freedom of access to and from the HOV lane. In the case of separated HOV lanes, access is restricted to designated areas. In the case of most concurrent flow lanes, eligible vehicles may move in or out of the HOV lane freely at any location. In fact, enforcement is often problematic on concurrent flow lanes because of the very fluidity of access and egress.

Overall, cross-sections for concurrent flow HOV lanes may be relatively wide if a full HOV shoulder is provided. The minimum cross-section for a contiguous concurrent flow facility consists of an 11-ft wide lane with a two- to three-ft offset to the median barrier. For safety, buffer areas should not be built at widths between 8 and 14 ft, because spaces in this range may be mistaken for breakdown areas, thus complicating, access and safety (Jacobson 1995). Priority access may be provided for HOVs and emergency vehicles, and all other normal freeway access points and lanes are also available to HOVs.

Where concurrent flow HOV lanes revert to general-purpose use during the off-peak, they should not be separated by buffers, and lane separation markings should be consistent with those of the general purpose lanes (Fuhs 1990). Signage stating the hours of operation should be prominent.

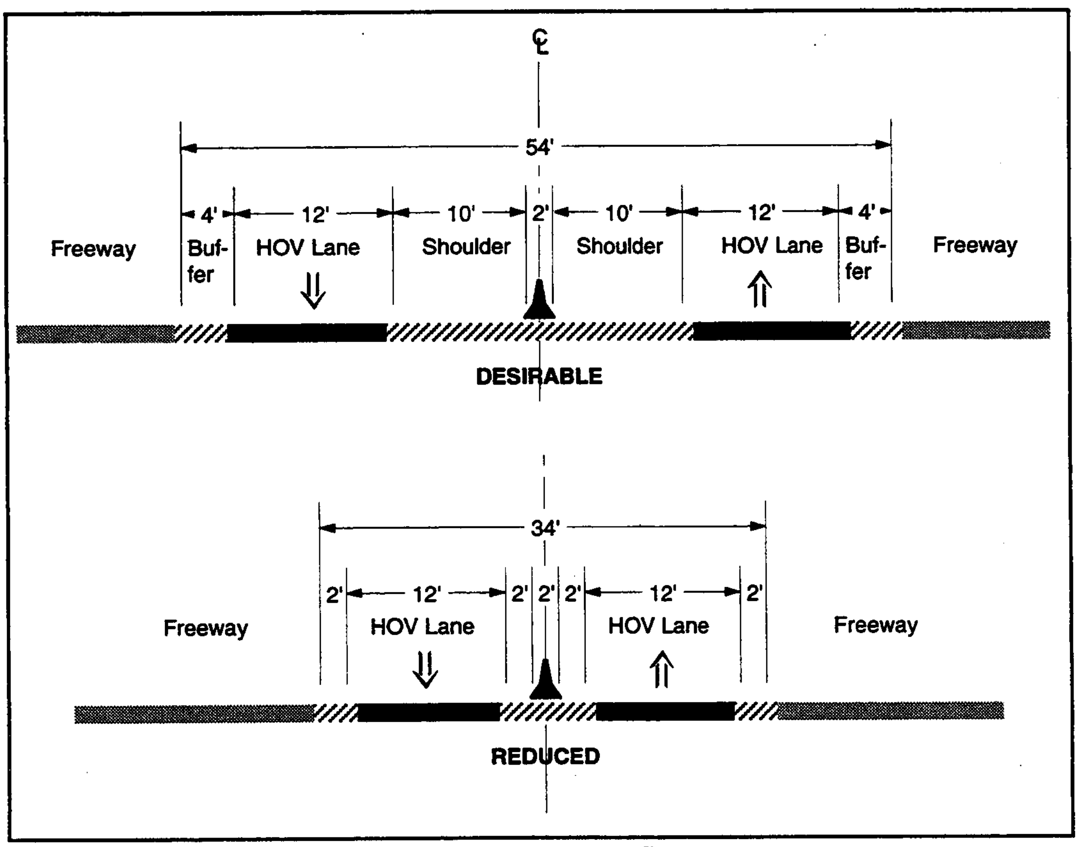


Fig. 37. *Recommended two-way, buffer-separated concurrent-flow cross-sections.*
Source: Fuhs (1990)

Contraflow HOV Lanes

Contraflow HOV facilities are inside freeway lanes converted to "wrong way" use for HOVs during peak periods. This type of lane conversion allows transportation agencies to take advantage of excess capacity in the off-peak direction. If implemented in conjunction with improved bus service, contraflow freeway lanes may substantially increase the person-miles of travel along heavily used corridors while reducing vehicle miles traveled (Orange County Transit District 1987). However, AASHTO (1992) cautions that contraflow lanes should not be implemented on a freeway with fewer than six lanes, and that the preexisting directional split should be heavily unbalanced (e.g., 70/30). This logical requirement for an unbalanced flow makes contraflow lanes more applicable to radial freeways than to beltways or ring roads. However, even where such excess capacity appears to be available, a contraflow lane should not be implemented if so doing would severely impede traffic flow in the off-peak direction (Fittante 1982).

Attention to striping and signage to indicate hours of operation and the contraflow lane's location vis-a-vis the other lanes is imperative. In addition, the speed limit on a contraflow facility should reflect the facility's maximum operating speed and geometry.

To date, contraflow lanes have been located along medians, such that they are not surrounded by opposite-moving traffic. Access to contraflow lanes is limited to specific "slip" ramps or crossover points, and removable barriers normally delineate the lanes. A buffer lane may separate the traffic on the contraflow facility from opposing freeway traffic. AASHTO (1992) reports that contraflow lanes should consist of, at minimum, a 12-ft lane and at least one full shoulder (fig. 38).

Contraflow lanes are customarily restricted to buses, vanpools, and taxis. Buses are the optimal contraflow lane users for several reasons. First, if the lane is dedicated to buses, then the traffic stream is homogenous, variation in vehicle performance is minimal, and there is no need for passing slower vehicles. Second, buses are highly visible to drivers on adjacent, opposite-moving lanes, especially when emergency flashers are used. Third, professional bus drivers are specially trained. Finally, bus lane volumes are relatively low (generally under 200 vehicles per hour), which reduces the risk of a collision between buses on the contraflow lane and vehicles in adjacent general purpose lanes (Levinson, Adams, and Hoey 1975). The minimum number of buses required to warrant a contraflow lane is based on speed-volume relationships identified in the *Highway Capacity Manual* (Table 13).

Because of the interaction with reverse-flow traffic, contraflow lanes are usually seen as an interim, rather than permanent solution for congestion. As congestion increases, non-peak directional traffic also tends to increase, which may force restoration of a contraflow lane to general purpose use. Contraflow operations are costly because of the required daily movement of cones, flexible posts, or barriers. Although erection of a permanent barrier is possible, the drawback is diminished flexibility in restoring the contraflow lane to regular operations in the event that this becomes necessary.

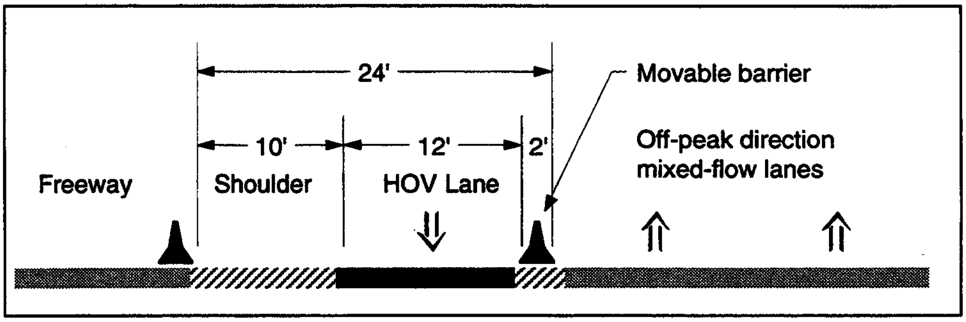


Fig. 38. *Recommended contraflow cross-sections*
Source: Fuhs (1990)

Table 13. *Approximate Minimum Bus Volumes Required for Contraflow Bus Lanes. Source: Levinson, Adams, and Hoey (1975)*

Tot. Peak Direction Demand (veh/hr)	Minimum Bus Volume Required for Off-Peak Direction Volume (veh/hr) of: 900	1,200	1,500	1,800	2,100	2,400	2,700	3,000	3,300	3,600	3,900	4,200	4,500
3,600	34	41	90	135	205	288	365	495	693	1,701	3,130	5,355	7,594
3,900	14	22	36	54	82	115	146	198	277	680	1,252	2,142	3,038
4,200	10	17	28	42	63	89	112	152	213	524	963	1,648	2,337
4,500	8	13	21	32	48	68	86	116	163	401	736	1,260	1,787
4,800	5	9	14	22	33	46	58	79	111	272	501	857	1,215
5,100	4	6	10	15	23	32	41	55	77	189	342	595	844
5,400	2	3	5	8	12	17	22	30	42	102	187	320	454
6,300	1	1	2	3	4	6	8	11	15	37	68	117	166
7,200	1	1	1	2	3	4	5	6	9	23	42	72	103
8,100	–	–	–	1	1	2	2	4	5	13	23	40	57

Notes: a. Assumes an occupancy factor of 1.5 and 50 for automobiles and buses, respectively.
b. Bus volumes exceed practical application of most urban bus fleets.
c. Involves hourly bus volumes ranging from 40 to 200 and falls within domain of practical application.
d. Bus volumes under 40 buses per hour do not usually warrant contra-flow lanes.

Temporary Use of Shoulders for HOVs

In addition to separated HOV lanes, concurrent flow lanes, and contraflow lanes, some transportation agencies have found that they can accommodate increased roadway demand by temporarily converting shoulders to HOV use (fig. 38). Given that shoulders are already used as travel lanes in many areas during construction, peak-period use of shoulders as HOV lanes is not unprecedented.

Shoulders can be converted to HOV lanes quite rapidly and may serve as a stopgap solution until a permanent HOV facility can be built, as in Washington state, where shoulders on I-405 and SR-520 have been converted to HOV lanes. Long-range plans for these corridors include full-fledged HOV facilities (Jacobson 1995). One benefit of this temporary solution has been improved transit travel time reliability.

As with any type of transportation project, shoulder conversion entails trade-offs. Some advantages are associated with shoulder conversion (Urbanik 1994):

- Shoulder conversion allows addition of a lane between ramps during peak periods without having to construct additional roadway.
- Shoulder conversion can give HOVs a queue bypass at exit ramps (i.e., HOVs may use the shoulder to exit, while other drivers must wait in the queue).
- Shoulder conversion allows some clearing of bottlenecks that are due to roadway geometrics by allowing increased flow through the corridor.
- Shoulder conversion reduces merging conflicts by giving entering vehicles a less congested area in which to merge and accelerate to freeway speed.
- Shoulder conversion allows creation of HOV lanes in some areas where they would otherwise be infeasible, while still maintaining an adequate number of general purpose lanes.
- Shoulder conversion mitigates the traffic impact of closing one or more lanes for maintenance or construction

Fig. 39. *Shoulders are sometimes used as travel lanes by HOVs during peak periods*

The following disadvantages are associated with shoulder conversion (Fuhs 1990):

- Emergencies and incident management require special care. Unless an obvious alternative is provided, motorists will tend to continue to use shoulders for emergencies, posing an acute safety hazard in that HOVs are simultaneously using them as a travel lane. To address this problem, the transportation agency in northern Virginia constructed additional "pull off" areas on I-66 for emergency use during hours of HOV operations.
- Signage and pavement markings must be carefully designed to avoid confusion.
- Lack of space may render law enforcement hazardous.
- Because shoulders on most freeways are not designed for intensive, all-day use, expensive pavement upgrades may be necessary.

BROAD PLANNING ISSUES

The HOV concept has many attractive qualities, chief among them the ability to make more efficient use of existing capacity at a relatively low capital cost. However, it not universally applicable. Fuhs (1990) compiled fatal flaw criteria from four of the states most active in developing HOV systems: California, New York, Texas, and Washington. These criteria are weighted against corridor-specific data pertaining to areas such as the following:

- origins and destinations along the corridor, including average trip length and travel time
- the nature of traffic flows along the corridor and parallel routes
- the cause, length, and location of incidents and bottlenecks
- vehicle occupancy, i.e., the percentage of 2+ and 3+ carpools already using the facility
- growth and land use factors along the corridor and parallel routes
- the transit mode split along the corridor
- the existing mainline design, with attention to geometric, topographical, and operational constraints

Four of Fuhs's chief fatal flaw criteria are discussed below. Combined, they criteria reflect evolving assumptions regarding HOV facilities' purpose and role in the transportation system.

Congestion. An HOV facility is indicated only if congestion is both severe and recurring (i.e., LOS E or F). Congestion should be serious enough to keep speeds under 30 mph during the peak hour and under 35 mph through the peak period. AASHTO specifies that a significant volume of peak-period trips (approximately 6,000 home-based work trips during the peak hour) should exist for the facility in question and that between 65 and 75 percent of the peak period trips should be over five miles long (AASHTO 1992).

Time Savings. Since the primary incentive to rideshare on an HOV facility is a reliable travel time advantage, it would not be effective to implement an HOV facility where such an advantage could not be achieved. Because driving alone is inexpensive in terms of out-of-pocket costs and flexible to individual needs, the HOV travel time advantage is critical in maintaining the facility's viability. "The single most important predictor of success of an HOV lane is its ability to reduce travel time and to generate reliable travel times to users" (Fuhs 1990).

Person throughput. While the need to provide an HOV travel time advantage is a given, state DOTs and related agencies cannot, for reasons both practical and political, pursue this goal at undue cost to SOVs. As such, it is generally agreed that the number of people projected to use the HOV lane should be at least equal the number carried in adjacent mixed-use lanes in the same direction.

Vehicle throughput. Fuhs sets separate vehicle throughput thresholds for both suburban- and radially-oriented HOV facilities. For suburban-oriented lanes, the threshold is 400 to 800 vehicles per peak hour, and for radially-oriented lanes it is 450 vehicles per hour (fewer if bus volumes are high). It is recommended that maximum vehicle throughput not exceed 1,500 vehicles per hour.

Retrofitting or New Construction?

Among transportation planners' initial considerations is whether an HOV facility should be created through new construction, which may require acquisition of additional right-of-way, or through retrofitting, wherein existing roadway features are modified. Trade-offs are associated with both options.

New construction has two significant advantages. First, it may be easier to adhere to desirable (as opposed to minimally acceptable) design standards in areas such as lane and buffer width. Second, building a new lane for HOVs means that nothing is "taken away" from existing general purpose lanes with an existing user base. Fuhs warns that, "...it is generally recognized that a lane addition is highly recommended, and that taking away a lane from mixed-flow traffic is not recommended. Taking away a lane or lanes should never create a condition in which the resulting improvement in level of service for HOV is offset by a lower level of service or increased delays to mixed-flow traffic" (Fuhs 1990). The disadvantages of new construction, on the other hand, are extremely high costs for right-of-way and construction, physical and topographical obstacles, and adverse environmental impacts related to both construction and the addition of new capacity.

It is much more common to create HOV lanes by retrofitting, which usually involves, at a minimum, resurfacing, restriping, partial paving, and special signing. The chief advantages of retrofitting are its much lower costs and impacts.

Inside vs. Outside HOV Lanes

Placing the HOV lane in relation to the freeway median is another important decision. Basically two options exist: inside or outside (fig. 40).

Although many transit operators prefer outside HOV lane placement with limited access, only about 10 percent of HOV lanes are located on the outside (Ulberg 1992). The advantage of the outside location from a transit perspective is that it eliminates the need to merge across multiple general purpose lanes to reach the HOV lane. Buses find this maneuver particularly difficult because of their size, longer turning radii, and lower speeds and acceleration ability. On the other hand, outside placement is disadvantageous in that it places buses and carpools into direct and fairly continuous contact with traffic that is entering or exiting the freeway. This mixture of HOVs and entering and exiting

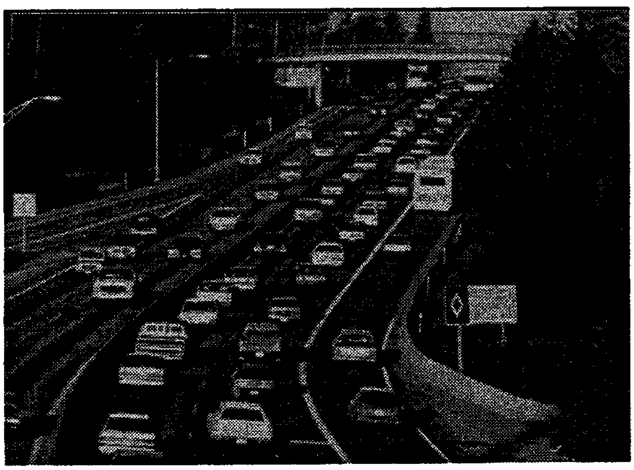


Fig. 40. *Inside HOV lanes are on the left-hand side of the freeway, and outside HOV lanes are on the right.*

general purpose traffic may worsen congestion (Ulberg 1992). For these reasons, it is important to install special signage, indicating where it is permissible for general purpose traffic to use the HOV lane to merge or exit. The minimum distance in which general purpose traffic should be allowed to merge from an on-ramp, through an outside HOV lane, and into the general purpose lanes is 1,200 ft, while the minimum that general purpose traffic should be allowed to use an outside HOV lane for exiting the freeway is 1,030 ft (Simpson 1995).

Although inside placement has the drawback of forcing buses and other HOVs to weave across multiple general purpose lanes, this is less of an issue on long, "straight shot" freeway trips characterized by few departures from the HOV lane. For such long-haul trips, the inside location frees HOVs from conflicts with merging traffic. In addition, occupancy violations are less common on inside lanes since ineligible vehicles have no excuse for being in the HOV lane. On the other hand, non-eligible vehicles on outside HOV lanes may claim that they were in the HOV lane only because they were in the process of merging onto or off of a freeway ramp. Without direct access, transit will find it difficult to take advantage of inside HOV lanes for short trips in congested conditions.

Occupancy Requirements

A trend of some concern to transit agencies is the gradual relaxation of occupancy requirements on HOV facilities. While some HOV projects were originally dedicated to buses, only two occupants are required on most North American HOV facilities (Table 14).

Relaxing HOV lane occupancy requirements is thought to negatively impact transit operations in several ways. Besides the slowdowns due to increased volumes, defining carpools as 2+ rather than 3+ may hasten the dissolution of 3+ carpools, and the defection of transit riders to 2+ carpools. In addition, enforcement is more difficult on 2+ facilities. One problem is the difficulty of detecting the presence of small children. This means that the officer must stop the vehicle before issuing a citation. Several studies have considered the effects of relaxing occupancy requirements. Selected findings are summarized below.

Houston, Texas. In October 1984, when the first segment of the Katy Freeway Transitway opened, only buses and vanpools were allowed on the facility. Extensions were added over the next three years for a total of 11.5 HOV lane miles. When the occupancy requirement was relaxed to 2+, the average number of vehicles on the HOV lane during the AM peak vehicles jumped dramatically (to capacity), and carpools came to make up 96 percent of the vehicles on the lane. Because the increase in carpool volumes worsened congestion, the 3+ occupancy requirement was restored during peak periods in 1990 (Christensen and Ranft 1988; Wade, Christensen, and Morris 1992).

Table 14. *HOV Lane Occupancy Requirements*

State	City	HOV Facilities	Occupancy Requirement
Arizona	Phoenix	I-10; SR-202	2+
California	Counties: Alameda, Contra Costa, Los Angeles, Orange, Marin, San Diego, Santa Clara, San Mateo	I-880; I-80; I-580; I-680; SR-91; I-405; I-105; I-210; SR-57; US 101; I-5; SR-85; I-280; SR-2378; San Thomas Expressway; Montague Expressway	2+/3+
Colorado	Denver	I-25	2+
Connecticut	Hartford	I-84; I-91	2+
Florida	Ft. Lauderdale, Miami, Orlando	I-95; I-4	2+
Hawaii	Honolulu	Moanaloa Freeway; H-1; Kalanianaole Freeway; Kanekili Highway	2+
Massachusetts	Boston	I-93 NB; SE Expressway	2+
Minnesota	Minneapolis	I-395	2+
New York	New York City	Long Island Expressway, Cross Bronx Expressway, Gowanus Expressway	2+
Pennsylvania	Pittsburgh	I-279/579; Sourth Busway, East Busway	2+ (M-F); buses only
Texas	Houston	I-10 (Katy); I-45; US 290; US-59	3+ (2+ off-peak)
Virginia	Washington DC area	I-66 from Route 50 to DC line; I-395; I-95	2+
Washington	Seattle	I-5; I-90; I-405; SR-167; SR-520	2+/3+

Long Island, New York. The Long Island Expressway, which runs from the Queens Midtown Tunnel to the Queens/Nassau County border, is the only east-west limited access route serving Manhattan from Long Island. In an evaluation of low-cost alternatives to improve efficiency on this expressway, consultants were asked to model the effects of 2+ and 3+ occupancy requirements, comparing them to the status quo, which permitted only buses and registered vanpools in the HOV lane. Relaxing the requirement to allow 2+ carpools was not recommended because the researchers projected that the resulting vehicle volumes would exceed capacity, leading to "extremely poor conditions for an HOV lane with speeds of 30 mph or less" (Sucher 1994).

Seattle, Washington. Among the most useful studies of occupancy requirements' effects on HOV lane performance is the 1992 before-and-after study by Ulberg et al. on the I- 5 HOV lanes just north of Seattle. This study was sponsored by the Washington State Department of Transportation (WSDOT).

Although the report is notable for its careful methodology, the authors point out the difficulty, if not impossibility, of generalizing on the basis of a single corridor. The difficulty lies in trying to control for confounding, site-specific variables. Upstream bottlenecks, inclement weather, recent TDM implementation, or any of a host of other variables can affect travel times, volumes, and other outcomes. The study's chief advantage is that it capitalized on a rare opportunity to carry out a controlled "real world" experiment on the effects of changing occupancy requirements. Highlights of the study are presented in Table 15.

The researchers used a license-matching method along with induction loop data to gather information about vehicle occupancy, volumes, and travel times along selected study segments. They found that relaxing the occupancy requirement from 3+ to 2+ adversely affected HOV lane travel times and reduced average vehicle occupancy on the corridor.

Interestingly, there was little evidence that opening the HOV lane up to 2+ carpools benefited even general purpose lane drivers. In fact, travel times for both HOV lanes and general purpose lanes deteriorated following the change. Before the change, general purpose traffic took an average of 9.80 minutes to traverse the study segment. After the change, general purpose traffic took an average of 11.42 minutes. HOVs also suffered. Their average travel time along the segment slowed from 7.50 to 7.98 minutes, a 6.4 percent change.

The slower times observed for HOVs are easy to understand, but the slowing for SOVs upon gaining access to the HOV lane is counterintuitive. Ulberg et al. explain that this travel time deterioration as a function of several factors. First, it appears that reducing the incentive to form and maintain 3+ carpools greatly reduced this configuration's popularity. The researchers found that the percentage of 3+ carpools on the facility

Table 15. *Highlights of Study by Ulberg et al. (1992)*

	HOV	General Purpose
Vehicle Volumes	Significant increase in peak hour volumes from approx. 400-500 to 1,200-1,400, or about 200%	Remained about the same
Vehicle Occupancy	Declined because of more 2-person carpools and fewer 3-person carpools	Remained about the same
Travel Times	Morning peak hour travel times have remained about the same, but afternoon peak hour times have worsened	Morning peak hour times, have improved, and afternoon peak hour times have worsened
Travel Time Reliability	HOV travel time reliability has decreased, especially in the afternoon peak hour	Travel time reliability in the general purpose lanes has remained about the same in the morning, but appears to have declined slightly in the afternoon peak hour

fell from about four percent to one percent following the change. Second, overall vehicle throughput rose. "The increase in SOVs probably comes from several sources, including shifts from parallel arterials, shifts from earlier and later time periods, and latent demand filling additional capacity, as well as the breakup of carpools and people shifting from transit" (Ulberg et al. 1992).

WSDOT asked the researchers to relate their findings to the state's transportation policy plan, the Clean Air Act, and the state's Commute Trip Reduction Act. Their conclusion was that the change from the 3+ designation to 2+ served the objectives of none of these statutes well. Regarding the state transportation policy plan, they responded, "This State Transportation Policy Plan emphasizes the movement of people rather than vehicles and advocates the provision of cost-effective alternatives to one-person vehicles, including transit and ridesharing. To the extent that the 2+ demonstration has resulted in more vehicles on the facility and lowered the overall vehicle occupancy rate, the results are counter to this plan."

With regard to the federal Clean Air Act Amendments and the state's Commute Trip Reduction Act, they concluded, "To the extent that more vehicles are moving through the I-5 corridor due to the reduction in 3+ carpool, and to the extent that a degradation in the travel times and travel time reliability for HOVs have occurred, the demonstration is less supportive of these acts than the 3+ requirement." These findings notwithstanding, the HOV lanes on I-5 have not been restored to a 3+ designation—they remain at 2+, as do all HOV lanes in the Seattle metropolitan area with the exception of SR 520.

Public Involvement in Occupancy Policy

Whereas most day-to-day decisions regarding HOV lanes are of little interest to the general public, occupancy requirements are an exception. Transportation agencies have thus found it in their best interests to work closely with their constituencies in developing occupancy policy. Setting occupancy requirements places transportation agencies in the middle of two conflicting goals: (1) as a mediator among competing groups (e.g., automobile and transit commuters); and (2) as a technical leader responsible for delivering cost-effective policies and projects.

Over the past 30 years, public involvement in transportation projects has grown, evolving from neighborhood-based protests against highways and other projects to more proactive local planning. Federal, state, and local agencies now solicit communities' active involvement. "Experience has made painfully clear the repercussions of imposing urban land use decisions without community influence or consent." (Lowe 1995).

An article in *Innovations Briefs* concludes by pointing out the irony surrounding public debate over the appropriateness of HOV facilities. "For many years environmentalists championed high occupancy vehicle lanes as an embodiment of progressive transportation planning that would finally shift emphasis "from counting vehicles to counting people" State highway departments, on the other hand, viewed HOVs with a mixture of skepticism and suspicion. Today, the roles are reversed: the highway establishment, having shed some of its old prejudices, has embraced HOV lanes as a necessary element of an enlightened transportation policy. It is environmental groups that now regard HOVs with suspicion, as only a slight step away from simply building new roads" (Urban Mobility Corporation 1996).

Encouragement of active public involvement in transportation projects and planning is codified in a number of federal laws, including the 1990 Clean Air Act Amendments, and the National Environmental Policy Act, as well as many state growth management, transportation, and environmental statutes. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) established expansive public participation rules for transportation planning.

ISTEA states that citizens, affected public agencies and jurisdictions, employee representatives of transportation and other affected agencies, and other interested parties, must be provided with reasonable notice of and an opportunity to comment on" the transportation improvement plan (TIP) and the long-range plan (ISTEA section 134, 135, and 23 CFR sec. 450.212). Such stipulations make it pragmatic for transportation agencies to involve the public in decision-making. Early attention to public involvement may avert costly, time-consuming conflicts.

HOV RAMP DESIGN

Current HOV design guidelines for connecting ramps focus primary on carpools; as such, they do not always take buses' particular needs into account. This section discusses ways that planners can incorporate the needs of transit into their designs for ramp bypasses and HOV exclusive-use ramps.

A synopsis of ramp-metering bypasses and exclusive-use ramps is provided as background on the varieties of ramps in operation. Design guidelines that specifically addresses the interface between (1) transit and ramp metering, and (2) transit and exclusive use ramps are then discussed. Notable design guidelines pertain to the effects of acceleration length and percentage grade on bus performance. Bus stop locations on ramps are mentioned briefly, and finally metering on HOV ramps is considered.

Two types of HOV ramps are used by buses: (1) ramp-metering bypasses, and (2) HOV-/transit-only ramps (exclusive use). There are several variations on each.

Ramp-metering bypasses. As of 1991, approximately 450 HOV bypass lanes were in operation (Dunn Engineering Associates 1991). Bypasses may be located to the left or right of metered traffic. Where feasible, it is preferable to locate the bypass on the left (PTI 1977). However, location on the left or the right is influenced by each sites' unique topographical, operational, political, and financial constraints. As such, every HOV ramp design—whether a retrofit or new construction—is site-specific (Fuhs 1990). Ramp installations should always be considered part of an integrated HOV system comprising freeways, streets, parking, and transit. Figure 41 represents a common layout for a HOV ramp meter bypass.

HOV- or transit-only ramps. Buses may operate on ramps reserved exclusively for buses or ramps serving both transit and carpools. Transit-only ramps are constructed to provide access that would otherwise be slow, circuitous, or impossible (Levinson, Adams, and Hoey 1975). Figures 42 through 44 depict characteristics of the following ramps: two-way drop, Texas T, and double flyover ramps.

Because HOV- and transit-only ramps are expensive, they must provide substantial time savings to justify their cost. The choice of which type of exclusive-use ramp to build depends on physical and financial constraints, and on whether the ramp is a retrofit or new construction. Physical constraints are usually more restrictive in the case of a retrofit, whereas finances usually constrain new construction.

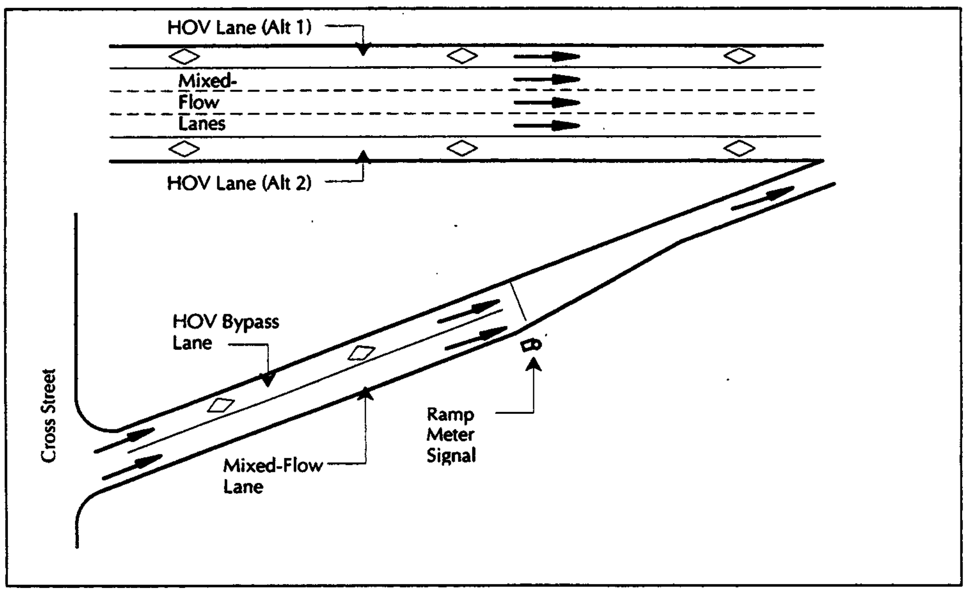


Figure 41. *Common ramp meter bypass layout*
Source: American Association of State Highway and Transportation Officials (1992)

Design considerations for HOV facilities include alignments, gradients, clearance, lane widths, transition lanes, cross-slows, and turning radii. These design considerations vary depending on the type of vehicle for which service is primarily intended.

The following discussion focuses on design issues as they apply to buses, comparing them with those of automobiles. Since facilities may be used by both buses and automobiles, whichever of the two has more stringent requirement is the controlling factor.

This comparison of design requirements for buses and passenger cars is based on two sources: the American Association of State Highway and Transportation Officials' (AASHTO) *Policy on Geometric Design of Highways and Streets* (1990); and John Mounce and Robert Stokes's *Manual for Planning, Designing and Operating Transitway Facilities in Texas* (1985). AASHTO was referenced for information on passenger cars, and Mounce and Stokes were referenced for information on buses. Additional sources with information specifically tailored to buses were also used, most notably Fuhs's *High-Occupancy Vehicle Facilities: Current Planning, Operation, and Design Manual* (1990).

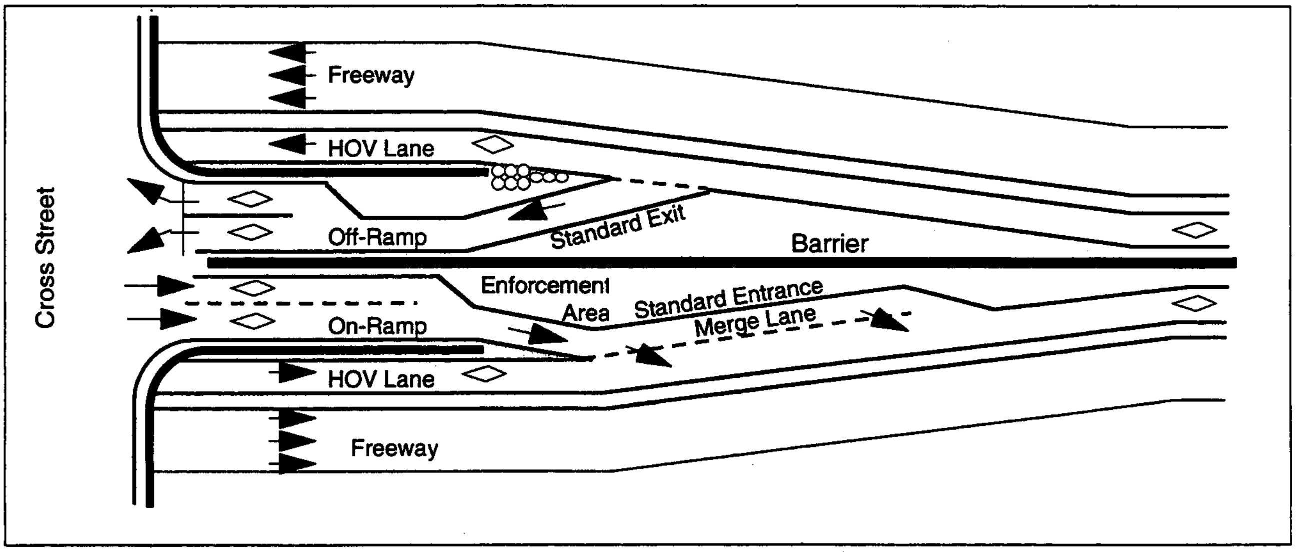


Figure 42. *Two-way drop ramp. The same design can be repeated on opposite side of overcrossing or undrecrossing street.*
Source: American Association of State Highway and Transportation Officials (1992)

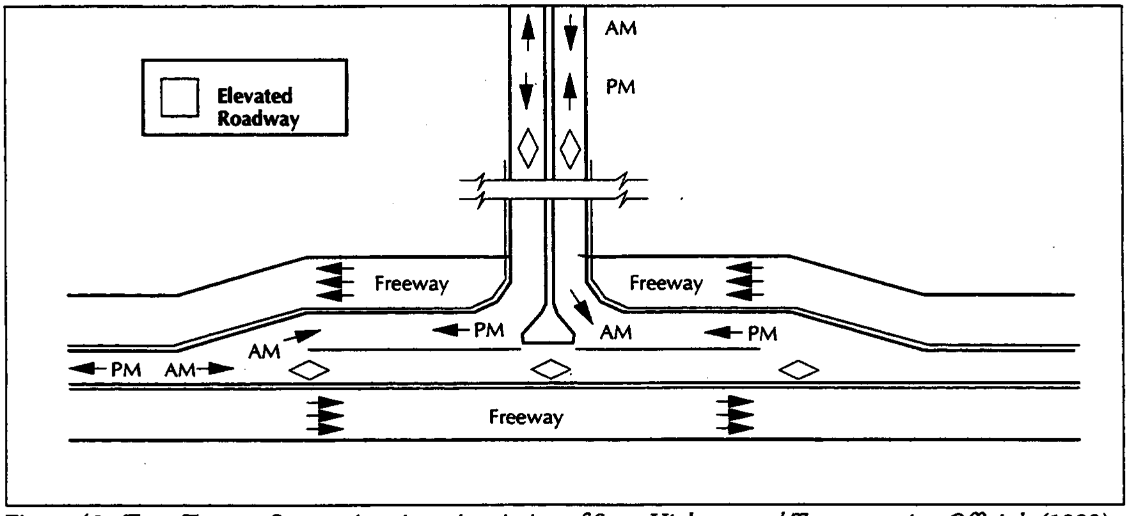


Figure 43. *Texas T-ramp. Source: American Association of State Highway and Transportation Officials (1992)*

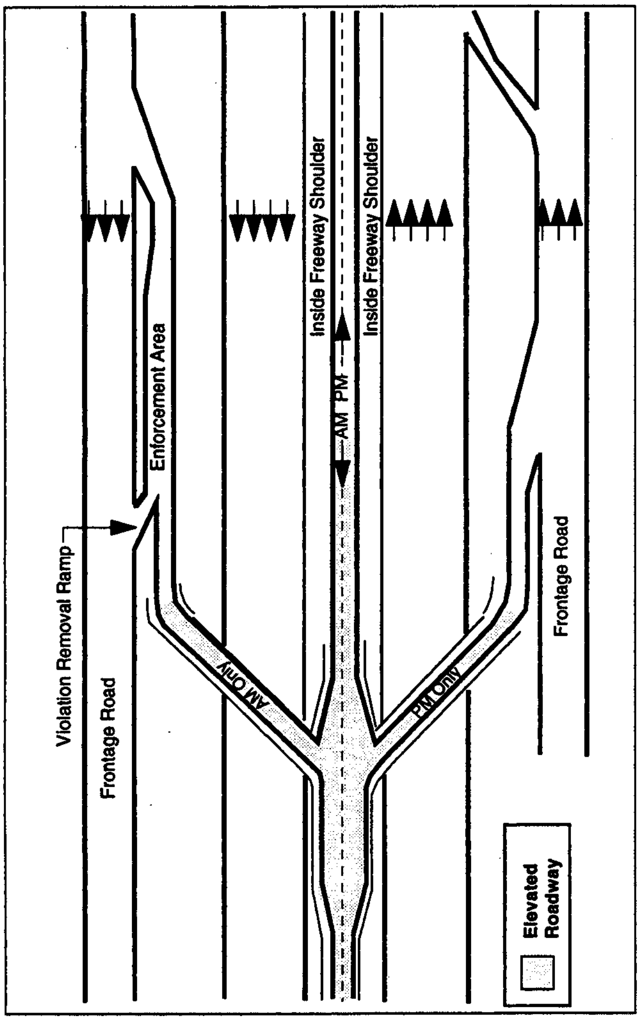


Figure 44. *Double flyover ramp. Source: American Association of State Highway and Transportation Officials (1992)*

Alignment

Alignment encompasses five design categories:

- Stopping sight distance
- Horizontal curvature
- Superelevation
- Crest vertical curvature
- Sag vertical curvature

Stopping sight distance is controlled by passenger cars, because bus drivers can see hazards from farther away, because of the higher height-of-eye. AASHTO requires a stopping sight distance of between 276 ft and 325 ft for a design speed of 40 mph (1990).

The horizontal curvature recommendation is related to a maximum superelevation of 0.04 ft/ft and a design speed of 40 mph. The minimum radius for a 0.04 ft/ft superelevation is 575 ft (AASHTO 1990). Where physical constraints preclude a 575 ft radius, a 500 ft curve with a 0.06 ft/ft superelevation may be used (Mounce and Stokes 1985).

The ramp's superelevation should follow the AASHTO 0.04 ft/ft maximum superelevation chart. Providing such a flat superelevation may require large radii for some ramp installations. Because buses have a higher center of gravity than do passenger cars, the larger radii required by a 0.04 ft/ft maximum superelevation better accommodate buses. As noted, physical constraints may dictate a tighter radius. In such cases, a 0.06 ft/ft superelevation may be used (Mounce and Stokes 1985).

Crest vertical curvature requirements are governed by passenger cars. Height-of-eye is an important factor in vertical curvature requirements. Passenger cars have a height-of-eye of 3 ft 6 in compared to buses' height-of-eye of 7 ft 3 in (METRO 1985). Because the bus driver's height-of-eye is twice that of a passenger car, bus drivers can better see obstacles over vertical curves. Therefore, passenger cars govern crest vertical curvature requirements (AASHTO 1990).

Sag vertical constraints are computed from AASHTO by calculating how far headlights will extend while passing through a sag vertical curve. Buses' headlights are higher than a passenger car driver's, which gives buses better visibility. Thus, passenger cars control for sag vertical curves as well.

Gradients

Gradients are governed by buses' capabilities. The maximum grade allowable is 6 percent, for a maximum length of 755 ft (Fuhs 1990). A minimum grade of 0.3 percent ensures adequate drainage (AASHTO 1990). Bus performance is greatly diminished by a 6 percent grade. Most buses (28-ft diesel, 40-ft diesel, and CNG, 60-ft diesel articulate) can maintain average speeds of only 30 mph at a 6 percent grade (ABTC 1994). Buses moving at 30 mph on a 55 mph facility can slow traffic significantly. Therefore, it is important to keep grades to a minimum to maintain high bus speeds and performance, so that buses can merge smoothly with the mainline.

Data from the Altoona Bus Testing Center were used to determine the average grade at which a bus can maintain a speed of 45 mph (45 mph represents a speed reduction warrant of 15 mph on a 60 mph facility). Each report from Altoona has a gradeability chart that gives the maximum speed obtained at certain grades. The average speed is 45 mph on a grade of 3 percent. This indicates that if the speed reduction warrant is 15 mph for a 60 mph HOV facility, then the maximum grade for an entrance ramp would be approximately 3 percent. Anything steeper will keep buses from reaching 45 mph. Unfortunately, the Altoona data did not include information on the distance required for buses to reach 45 mph on a 3 percent grade. Additional research on bus acceleration as a function of grade and distance would thus be useful.

Where it would be difficult to provide a grade as gentle as 3 percent, one option is to build a ramp with an initial steep grade that quickly flattens out. The flat portion could then be at a 3 percent grade for a distance that would allow buses to reach a safe merging speed. However, such a design could present sight distance problems for auto drivers, whose height-of-eye is lower.

Clearance

AASHTO recommends a 16-ft vertical clearance for HOV facilities (1990). This clearance is adequate for diesel buses and trolley buses such as Seattle's, which require a minimum clearance of 16 ft (PBQD 1985).

Right-side lateral clearances should extend from 8 ft to 10 ft (AASHTO 1990). Left shoulder clearances should be either 4 ft or 10 ft because drivers may mistake should widths between these values for emergency parking (Fuhs 1990). In total, the pavement should be wide enough to allow for passing stalled vehicles (Fuhs 1990). A lane width of 13 ft is recommended for HOV ramps (Mounce and Stokes 1985), although a 12-ft width is acceptable (Lomax and Fuhs 1993).

Transition Lanes

Acceleration length. Compared to passenger cars, buses accelerate poorly. AASHTO requirements are 1,170 ft (design speed of 60 mph) for the acceleration distance, plus a minimum of 300 ft taper (AASHTO 1990). Figure 45 depicts the comparison of buses 40' and smaller to 60' articulated buses.

One drawback of long acceleration lengths bears mention. Automobile drivers tend to use the long acceleration lengths as passing zones in stop-and-go traffic. When the mainline is stopped, some drivers will pull into the acceleration/merging portion of the ramp to drive to the end of the ramp taper before merging back into the mainline. Because this raises safety issues, it should be taken into account when considering acceleration distance.

The nature of the Altoona a data make it impossible to determine the change in acceleration distances for different grades. As noted, buses do not perform well on upgrades; as such, acceleration length needs to be increased on ramps built on upgrades. However, more research would be necessary to ascertain the precise addition necessary.

Deceleration length. AASHTO recommends a minimum deceleration length of 532 ft (for a final stopped condition and mainline design speed of 60 mph) plus an additional 390 ft for a 30:1 exit taper (assuming a 13 ft lane width) (AASHTO 1990). Mounce recommends a 325 ft deceleration length plus an additional 390 ft for a 30:1 exit taper (assuming a 13-ft lane width) (Mounce and Stokes 1985) Deceleration length may be corrected for grade according to Table 16 (AASHTO 1990).

Exit and Entrance Tapers. AASHTO and Mounce recommend the same exit and entrance tapers. A 50:1 ratio is recommenced for the entrance taper, and a 30:1 ratio for the exit taper (Mounce and Stokes 1985).

Turning Radius

The turning radius required at a ramp is governed by 40-ft single-unit buses. Although 60-ft articulated buses are longer, their center hinge allows them to turn more sharply (Mounce and Stokes 1985). The recommended turning radius for a 40-ft single-unit bus is 55 ft for a 90 degree right turn at the entrance to ramps (AASHTO 1990). A turning radius of 55 ft, rather than the more standard 50-ft radius, gives single-unit buses

Table 16. *Deceleration Length Adjustment Factors as a Function of Grade. Source: American Association of state Highway and Transportation Officials*

Design Speed of Highway (mph)	**Deceleration Lanes Ratio of Length of Grade to Length on Level for Design Speed of Turning Roadway Curve (mph)**	
All speeds	3% to 4% upgrade 0.9	3% to 4% downgrade 1.2
All speeds	5% to 6% upgrade 0.8	5% to 6% downgrade 1.35

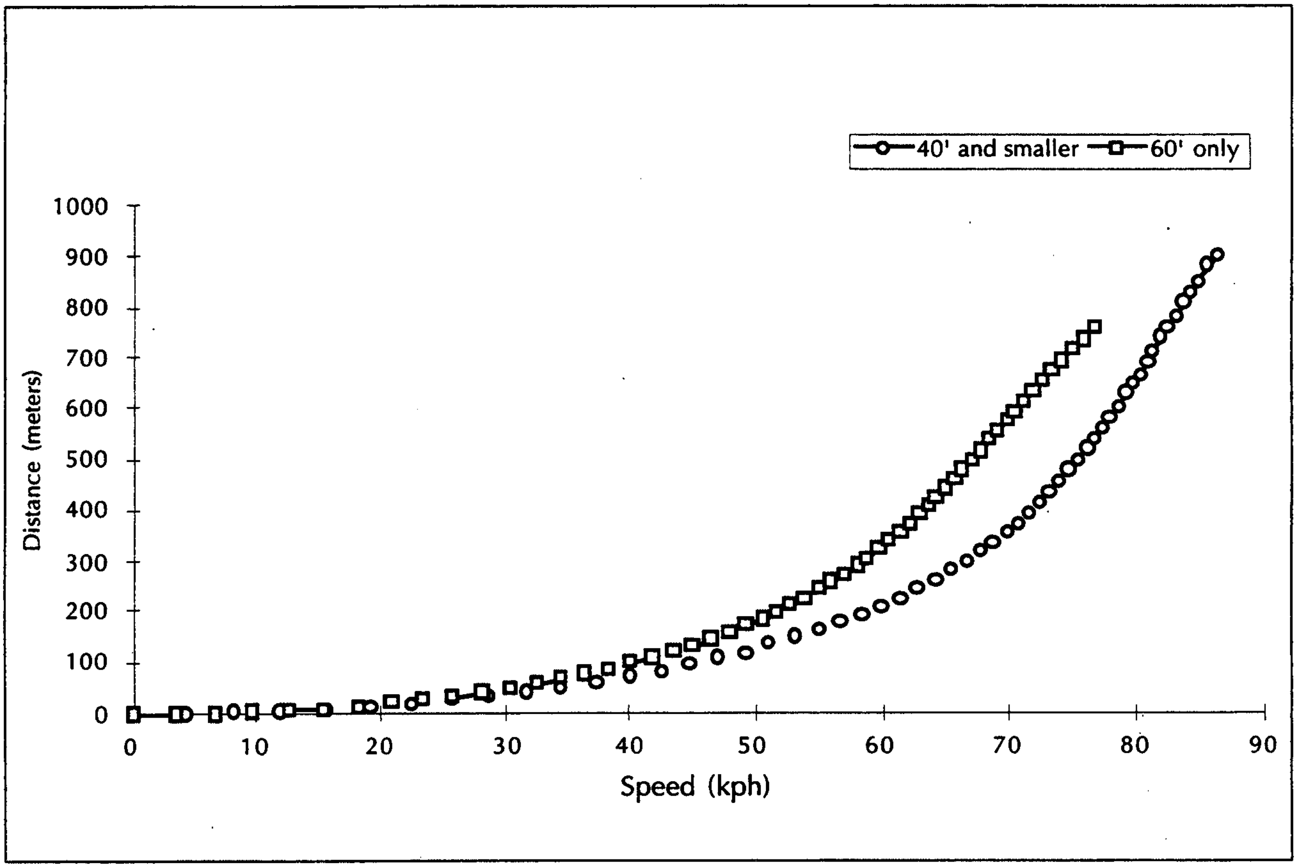


Figure 45. *Speed versus distance comparison of 40-ft and 60-ft articulated buses*

slightly more clearance at the far end of the curve (AASHTO 1990).

Should Bypasses be Metered?

Transit ramp-metering bypasses and transit-only ramps should not be metered unless ramp volumes become so heavy that they impede mainline traffic (PTI 1977). However, if ramp meter bypasses must be signalized, the bypass should be metered at a faster rate then the mixed-flow signal because of the importance of preserving the time incentive for HOV passengers. If the facility is used by carpools as well as transit, an alternative to metering is to raise the carpool occupancy requirement.

If bypasses must be metered, then the acceleration characteristics presented in the design portion of this paper should be considered, and adequate distance should be provided accordingly.

PLANNING

Determining whether an HOV ramp is justified at a given location requires consideration of many elements, some of which are quite difficult to quantify (Biemborn 1993). Nonetheless, a relatively simple cost-benefit analysis of time saved provides a baseline against which capital costs may be compared.

Cost/Benefit Analysis

Cost/benefit analysis provides a means of comparing project costs to anticipated benefits. In the case of transportation improvements, capturing all benefits in simple financial terms is not easy. Since time savings and the monetary value of time saved can be calculated relatively easily, it is not unduly difficult to run a cost/benefit analysis that defines cost as capital investment and benefit as the present value of time saved. Therefore, analyzing the monetary benefits of an HOV bypass or exclusive-use installation, with respect to the amount of time savings it provides the users, can sketch out how much capital investment is justified based on the present value of time saved.

Table 17 is a spreadsheet that provides a present value of annual benefits resulting from time saved. The resulting present value indicates how much capital expense is warranted based solely on the estimated amount of time saved. While the spreadsheet includes inputs for both carpools and buses, it may be used as bus-only indicator if a value of zero is used for the number of carpools per peak and off-peak hours.

The spreadsheet can be modified to reflect low, medium, and high use estimates. Table 17 reflects a hypothetical situation wherein values for passengers per bus, number of buses, and number of carpools are varied over a range of values. The results are in the calculations portion of the spreadsheet. This procedure can be used to observe the effect of given variables on the total present value.

Spreadsheet Inputs

The spreadsheet requires the following inputs:

- operating costs of buses
- value of bus passenger's time
- passengers per bus per peak hour
- passengers per bus per off-peak hour
- number of buses per peak hour, number of buses per off-peak hour
- operating cost of carpools
- value of carpool passenger's time
- passengers per carpool per peak hour
- passengers per carpool per off-peak hour
- number of carpools per peak hour
- number of carpools per off-peak hour
- effective interest rate (if money was invested rather than spent)
- the ramp installation's expected life.

The remainder of the spreadsheet is computed automatically with the equations listed in Table 17. It is strongly recommended that the values used in the "GIVEN" portion of the spreadsheet be obtained from a local transit agency because regional values vary significantly. If the local transit agency is unable to provide these values, Table 18 presents some guidelines on alternatives.

Table 17. *Present Value Spreadsheet*

GIVEN:

	Units	Low Use	Med Use	High Use
Operating Cost (Bus) -- OCB	$/hr/bus	50	50	50
Value of Passenger's Time (Bus) -- VPTB	$/hr/pass	7	9	12
Passengers per Bus -- PPB	pass/bus	25	45	65
Number of Buses per Day -- NB	buses/day	50	95	125
Operating Cost (Carpool) -- OCC	$/hr/cp	10.15	10.15	10.15
Value of Passenger's Time (Carpool) -- VPTC	$/hr/pass	8	10	12
Passengers per Carpool -- PPC	pass/cp	2.25	2.25	2.25
Number of Carpools per Day -- NC	cp/day	50	100	150
Interest Rate -- i	%	7	7	7
Term -- n	years	20	20	20

EQUATIONS:

Benefits in $/yr = TS/60*((NB*251*(OCB+VPTB*PPB))+(NC*251*(OCC+VPTC*PCC)))

Present Value = {Benefits in $/yr}*((1+i)^n-1)/(i*(1+i)^n)

CALCULATIONS:

TS (min)	Present Value Low Use	Present Value Med Use	Present Value High Use	TS (min)	Present Value Low Use	Present Value Med Use	Present Value High Use
1.0	$560,959	$2,060,357	$4,844,987	3.1	$1,738,972	$6,387,108	$15,019,458
1.1	$617,055	$2,266,393	$5,329,485	3.2	$1,795,068	$6,593,144	$15,503,957
1.2	$673,151	$2,472,429	$5,813,984	3.3	$1,851,164	$6,799,180	$15,988,456
1.3	$729,246	$2,678,465	$6,298,483	3.4	$1,907,260	$7,005,215	$16,472,954
1.4	$785,342	$2,884,500	$6,782,981	3.5	$1,963,356	$7,211,251	$16,957,453
1.5	$841,438	$3,090,536	$7,267,480	3.6	$2,019,452	$7,417,287	$17,441,952
1.6	$897,534	$3,296,572	$7,751,979	3.7	$2,075,548	$7,623,323	$17,926,450
1.7	$953,630	$3,502,608	$8,236,477	3.8	$2,131,643	$7,829,358	$18,410,949
1.8	$1,009,726	$3,708,643	$8,720,976	3.9	$2,187,739	$8,035,394	$18,895,448
1.9	$1,065,822	$3,914,679	$9,205,474	4.0	$2,243,835	$8,241,430	$19,379,946
2.0	$1,121,918	$4,120,715	$9,689,973	4.1	$2,299,931	$8,447,465	$19,864,445
2.1	$1,178,013	$4,326,751	$10,174,472	4.2	$2,356,027	$8,653,501	$20,348,944
2.2	$1,234,109	$4,532,786	$10,658,970	4.3	$2,412,123	$8,859,537	$20,833,442
2.3	$1,290,205	$4,738,822	$11,143,469	4.4	$2,468,219	$9,065,573	$21,317,941
2.4	$1,346,301	$4,944,858	$11,627,968	4.5	$2,524,315	$9,271,608	$21,802,440
2.5	$1,402,397	$5,150,894	$12,112,466	4.6	$2,580,410	$9,477,644	$22,286,938
2.6	$1,458,493	$5,356,929	$12,596,965	4.7	$2,636,506	$9,683,680	$22,771,437
2.7	$1,514,589	$5,562,965	$13,081,464	4.8	$2,692,602	$9,889,716	$23,255,936
2.8	$1,570,685	$5,769,001	$13,565,962	4.9	$2,748,698	$10,095,751	$23,740,434
2.9	$1,626,780	$5,975,037	$14,050,461	5.0	$2,804,794	$10,301,787	$24,224,933
3.0	$1,682,876	$6,181,072	$14,534,960				

Table 18. *Cost/Benefit Analysis*

Bus Operating Cost ($ per hour per bus)	The Municipality of Metropolitan Seattle (METRO) has used a value of $50 to calculate the feasibility of installing a transit ramp in Kirkla d, WA.
Value of bus passenger time ($ per hour per passenger)	The value is regionally specific and sensitive to the type of service in question. The value for express service will likely be higher than that for non-express service. A value equivalent to one third of the region's average wage is commonly used (WSDOT Masuiti Programming Method).
Passengers per bus (peak and off-peak)	Again, this value is sensitive to a particular serve and is likely to be higher during peak periods than during the off-peak. Value can be based on the seating capacity of the type of bus using the facility. For reference the seating capacity for a 40' single bus is 45-51 passengers; for a 60' articulated bus, seating capacity is around 70 passengers. An engineering estimate is necessary to determine the percentage capacity. One study from Kirkland, WA, used an average of 25-30 passengers per bus.
Number of buses served (peak and off-peak)	These values are obtained from the transit agency that will use the facility. Changes in service resulting from the new ramp should be considered. This value is converted to a yearly number of buses by means of the following equation: Number of buses * 251 days/yr (365 days - 104 weekend days- 10 holidays). A value of $24,410 was used in Kirkland, WA.
Carpool operating cost	Based on a 29-cent per mile operating expense (State of Washington standard reimbursement value) and an average speed of 35 mph for the ramp, an estimated operating cost is $0.29 * 35 = $10.15 per hour per carpool.
Value of carpool passengers' time	Dollars per hour for carpools will likely be higher than bus ridership values. A value of $10 can be used.
Passengers per carpool (peak and off-peak)	Average number of passengers per carpool depends on the facility's occupation designation. Whereas a 3+ designation translated to 3.10 passengers per carpool, a 2+ designation translates to 2.25 passengers per carpool.
Number of carpools (peak and off-peak)	These values are highly speculative. The value is multiplied by 251 working days a year to get an approximate number of carpools per year (# of carpools * 251= 25,000 carpools per year).
Length of peak hour	This value should reflect the number of peak hours that the ramp will be utilized on a weekday. For example, if the ramp is utilized during the am peak only, the peak period will be two to three hours. However, if the ramp is reversible and will be utilized both am and pm peak, the value will be four and seven hours.
Interst rate	Also known as the discount rate, this value captures the expected return on an annuity if it were invested instead of spent on ramp construction. A value of seven percent is recommended by the U.S. Office of Business and Measurement.
Term	The useful life-span of a ramp.

Graphical Representation

The results of the cost/benefit analysis may be illustrated by graphing time savings along the x-axis and present value along the y-axis (Figure 46). Graphing the results in this format makes it easier to visualize the time savings needed to justify a given capital investment. For example, if each passenger's time savings estimate is 3 minutes, then one would estimate that a $1.7 million improvement would be justified in the low use case, and $14.5 million would be justified in the high use case.

Sensitivity Analysis

A sensitivity analysis of the "GIVEN" variables in Table 17 was conducted by varying one "GIVEN" while holding the rest constant. The sensitivity analysis showed that the value of bus passengers' time, the number of passengers per bus (peak and off-peak), the number of buses (peak and off-peak), and the length of peak hour have the greatest effect on the capital investment allowance. Note that the value of carpoolers' time, passengers per carpool, the number of carpoolers, and operating costs for both buses and carpools have little effect.

All of the off-peak variables are slightly sensitive because the variables are an average for 24 hours minus the length of peak hour. When formulating the off-peak variables, it is important to average the variable out over the remaining hours of the day.

The results of the sensitivity analysis indicate that carpools have a modest effect on the capital investment allowance. Varying the number of carpools from zero to 50 carpools/peak hour changes the capital investment allowance by only about $1 million (fig. 47).

The capital allowance is sensitive to the length of peak hour. However, if this variable is rounded to the

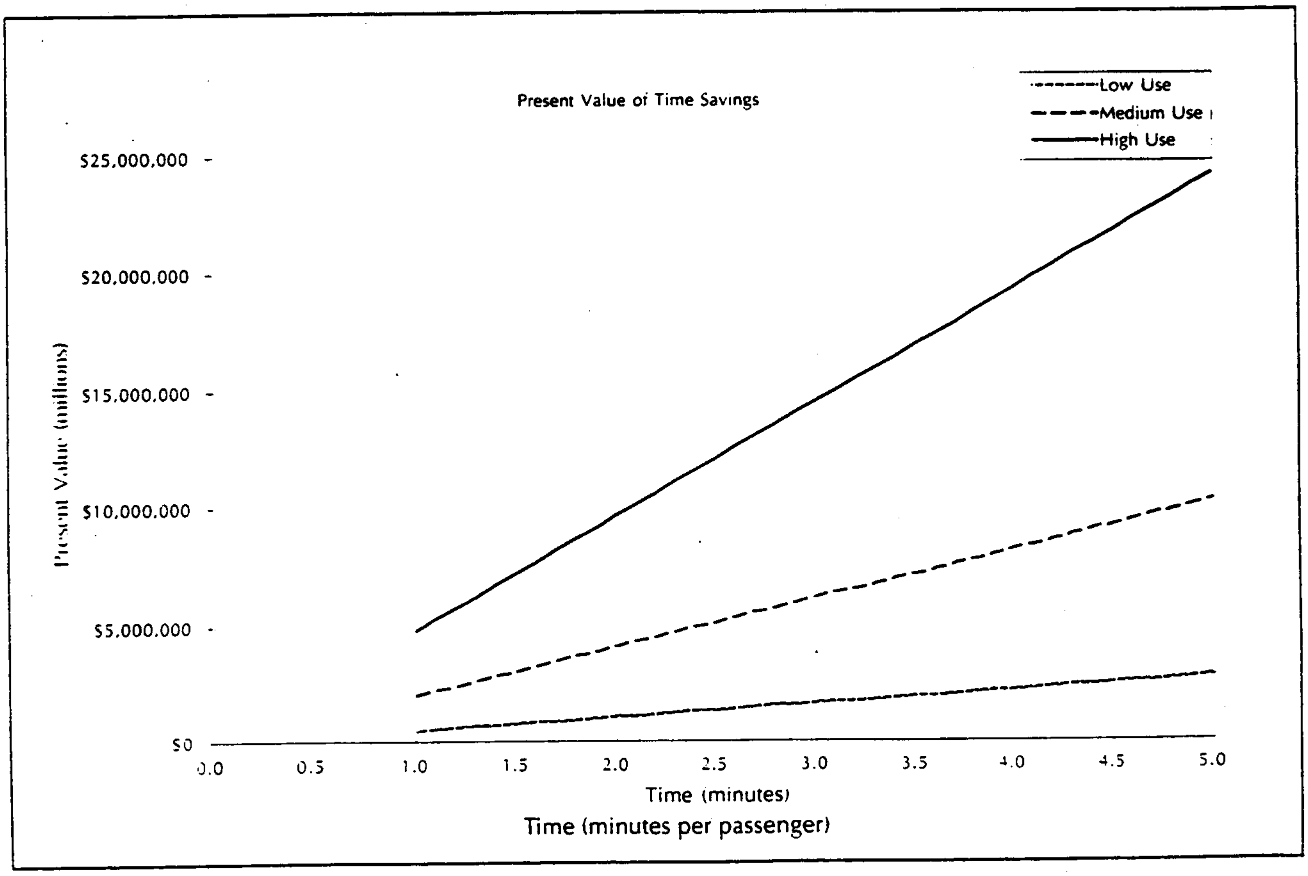


Figure 46. *Present value of time savings*

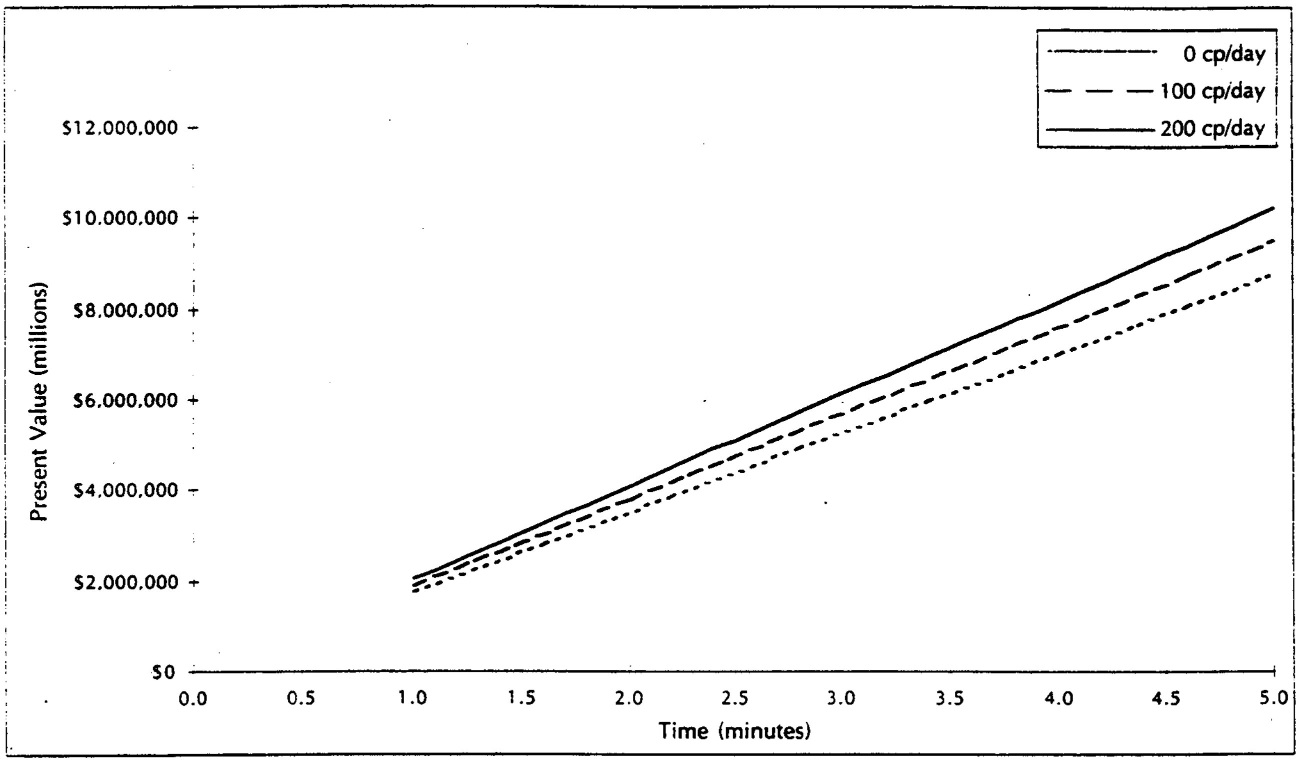


Figure 47. *Effects of number of carpools on present value*

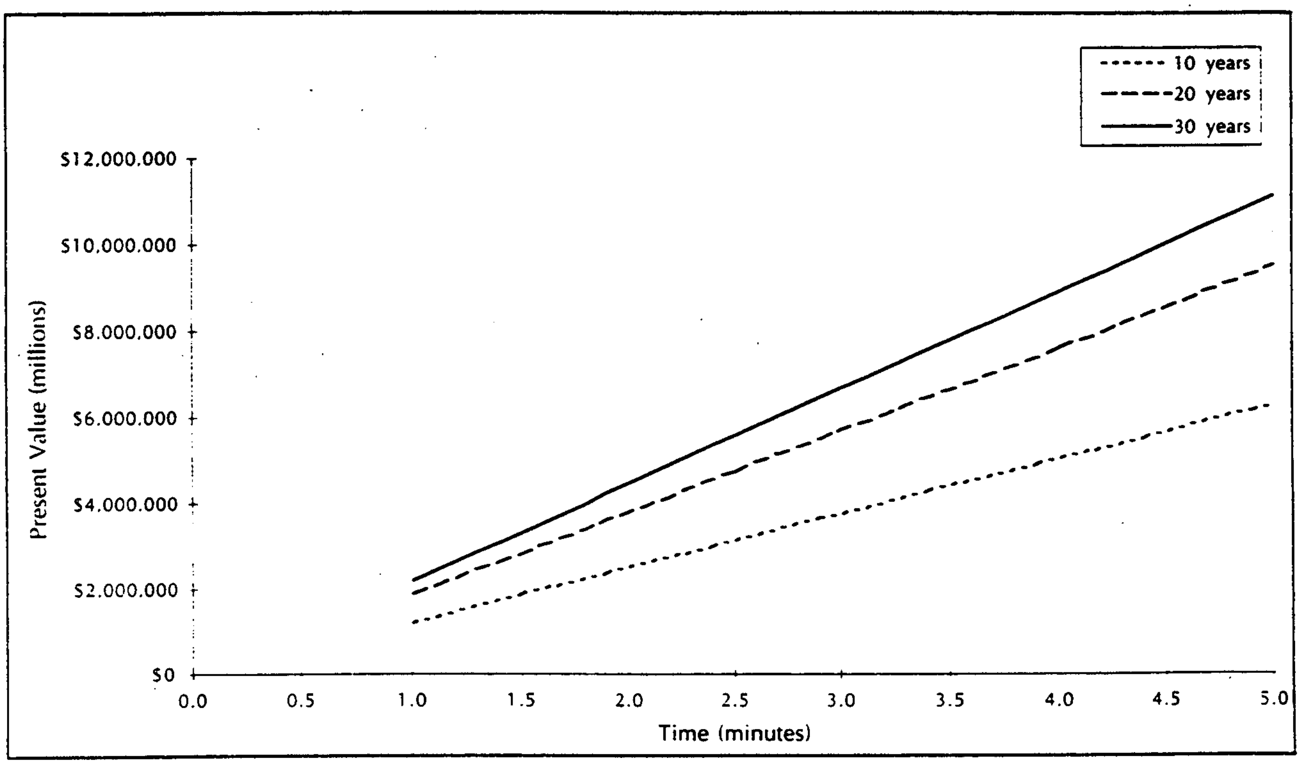


Figure 48. *Effect of change in term (expected life) on present value*

nearest half hour and fixed throughout the analysis, it should not pose a problem. Not surprisingly, the interest rate (i) also has a significant effect on the capital investment allowance. The prevailing interest rate can be obtained from the federal Office of Management and Budget.

The ramp's life expectancy is represented by (n) in the present value equation. Changing the term from ten to 20 years changes the capital investment allowance by $4 million (fig. 48). In comparison, changing the term from 20 to 30 years only changes the capital investment allowance by $2 million. Thus, it is more important to determine whether the structure will be used for 10 or 20 years than to determine whether it will be used for 20 or 30.

The sensitivity analysis indicates that some variables affect the present value of time savings more than others. The present value is quite sensitive to the following:

- the value of bus passengers' time
- the number of passengers per bus (peak and off-peak)
- the number of buses (peak and off-peak)
- the length of the peak hour

The present value of time savings is not particularly sensitive to these variables:

- the value of carpoolers' time
- passengers per carpool
- the number of carpoolers
- the operating costs of both buses and carpools

The analysis indicates that the values related to carpools are less significant for present value than the values related to buses. This matters because there is often a question as to how many carpools will use a ramp. This sensitivity analysis indicates that it is more important to be precise with regard to the factors related to buses than to those related to carpools. Although improving transit operations produces many benefits, such as decreased automobile trips and improved environmental quality, these benefits are difficult to quantify; as such, they are not captured in this form of cost/benefit analysis.

Any decision as to whether to make a capital investment to benefit transit also depends on the facility's perceived benefits (Biemborn 1993). In other words, if the ramp installation (and transit operation in general) is acceptable to the community that will pay for it, then that community will be less sensitive to cost. Although it is difficult to quantify a community's perception of potential ramp installation, a qualitative read can be taken by soliciting public and political input.

SAFETY

While it is generally agreed that the application of freeway design standards to the design of HOV facility access/egress is appropriate, there has been little consideration of this approach's safety impacts. Several variables can impact the level of safety experienced on a facility. Therefore, conclusions drawn from the literature cannot be directly applied to any situation other than the one specific to the study performed. However, safety-related literature can be used to provide overall insight into factors influencing the safety of an HOV facility for future evaluations.

Golob and Recker (1988) describe a number of factors with a bearing on HOV lane safety.

- visibility/sight distance
- adjacent general purpose (GP) congestion levels
- consistency of HOV lane position throughout corridor
- clarity of signing and striping and the maintenance of this signing and striping
- adjacent shoulder width, degree of physical separation from GP lanes
- HOV lane width
- enforcement presence

In *Operational and Safety Experience with Freeway HOV Facilities in California,* Newman, Nuworsoo, and May described a study that correlated accident rates with operational characteristics such as separation methods and HOV lane volumes (1988). The researchers found that concurrent flow HOV lanes, which are not separated from adjacent general purpose lanes by either physical structures or painted buffers, have higher accident rates because the potential for conflict exists at so many more points. In contrast, buffered or separated HOV lanes allow interaction only at those points designated by the responsible agency. The researchers also found that accident rates increase with volume (Newman, Nuworsoo, and May 1988).

Safety on Ramps

Although no individual HOV/transit bypass has been shown to increase the number of accidents at that specific location, when a series of bypasses on a section of freeway has been compared to the same series of ramps prior to the bypass, a slight increase in the accident rate has been observed (Beiswenger, Hoch & Associates 1979). This accident rate increase is not attributed to unsafe driving on the part of buses and carpools *per se*, but to the requirement of an additional merge beyond what would normally be necessary. For an ordinary mixed-flow ramp, vehicles have only to merge with the mainline. For a HOV/transit bypass, bypassing vehicles must merge once with the metered traffic and again with the mainline. This additional merge increases the potential for accidents. Providing adequate distance for both merges is therefore important for safety (Beiswenger, Hoch & Associates 1979). Safety performance of exclusive-use HOV ramps has not been studied; however, such research would be valuable.

Pedestrian safety at ramps with bus stops should be a high priority. Designers should ensure that their plans effectively prevent vehicles from mainline traffic from veering into pedestrians (McCormick Rankin 1990). The distance on the vertical access is the distance from the outside edge of the mainline and the inside edge of the bus lane. Considered in conjunction with the design speed of the facility, this distance can give an indication of the risk associated with a given distance from the mainline. Locations where the hazard is computed as "medium" or "high" are taken to warrant barrier construction to ensure the safety of pedestrians waiting at the bus stop.

Adequate acceleration length is also key in safe merging and weaving. Safety is improved where the merging vehicle's speed closely approaches mainline speed (AASHTO 1990).

ENFORCEMENT

Although Landy probably did not have HOV lane occupancy violation in mind when he characterized the human temptation to evade rules, his words are fitting in this context.

> Citizens are not always saints. They are prone to be law abiding and public spirited, but they do not like to be taken for chumps. If they observe others flouting the norms that they are struggling to abide by, their reserves of law abidingness will be sapped, and eventually they too will disobey. For the well-intentioned, there is no more bracing tonic than the sight of miscreants being punished (1993).

One way to improve safety is to step up enforcement (Billheimer 1990). Motorists are more likely to pay attention to their driving habits in the presence of an officer of the law. A Texas Transportation Institute study (TTI 1989) set forth three key concepts to ensure effective HOV enforcement, and by extension, a safer driving environment:

- The enforcement level needed depends on the HOV facility. Concurrent flow facilities generally require more enforcement than separated or contraflow facilities because of the ease of violating rules on concurrent flow lanes compared to separated or contraflow lanes, where ingress and egress are circumscribed.
- Officers need a safe, convenient place in which to issue citations. While there is value in issuing citations in plain sight of other drivers, enforcement should not interfere with normal traffic on the HOV or general purpose lanes.
- A highly visible enforcement presence should be maintained so that would-be violators and legitimate HOV lane users believe that violators have little chance of escaping detection.

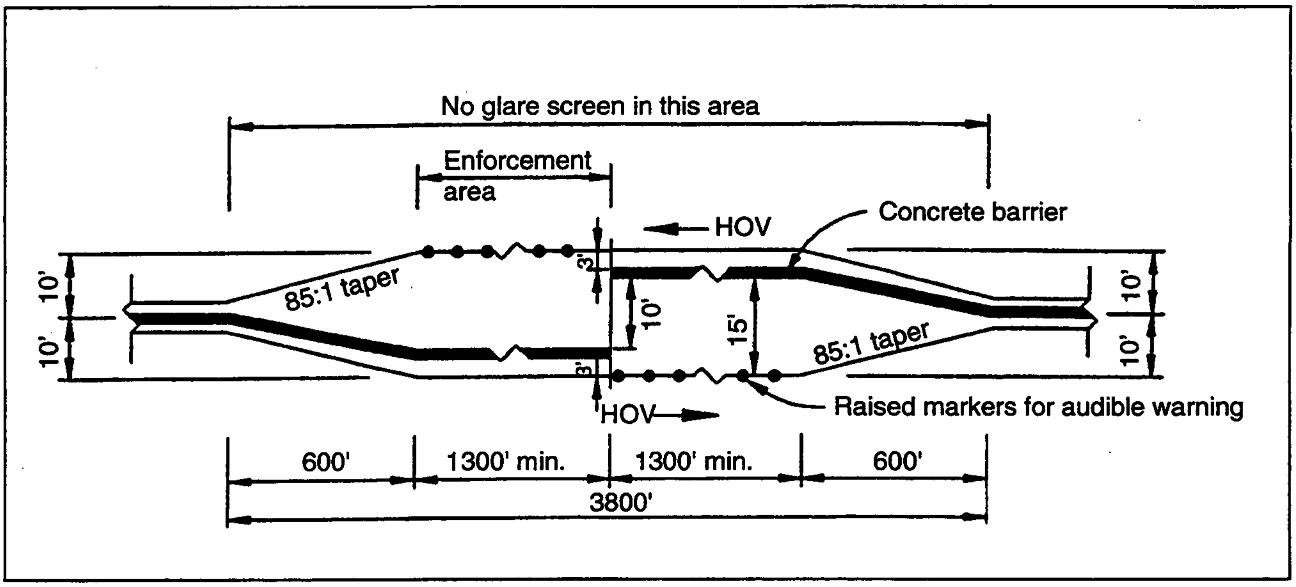


Figure 49. *Enforcement area design used on concurrent-flow HOV lanes in California. Source: Caltrans (1989) cited in Institute of Transportation Engineers (1992)*

Diverting violators from the HOV lane may be safer and more efficient than apprehending them immediately after the violation has occurred. Diversion or citation areas at terminal points and intermediate access points can provide visibility and locations for enforcement activity. Areas adjacent to the HOV lane have been implemented by Caltrans to provide a safe refuge area for both officer and violator (fig. 49).

HOV lane violation rates range widely, depending on several factors. An important variable is whether the HOV lane is physically separated from general purpose traffic. Physically separated HOV lanes generally experience lower levels of violation than do concurrent flow HOV lanes. Because the mere physical presence of law enforcement officers decreases the number of violators, HOV facilities should be designed with adequate space for troopers to pull violators over. Public perception of HOV lane violations can ultimately affect the public's support for lane operations. The perception that violation rates are high may erode public support for the HOV facility (Russel 1991).

Presented in Table 19 are the enforcement policies in effect on the nation's major HOV facilities. In all the states surveyed, state patrols or police departments were the primary enforcers. California was found to charge the highest fine for improper HOV lane use: $271 plus court costs for first time offenders. Fines for additional offenses are even higher: approximately $375 per offense. Colorado was found to charge the lowest fine: $35 to $50 plus court costs.

Hero and PHOTOCOP Programs

In addition to standard enforcement practices, such as patrolling HOV areas for violators, some jurisdictions have come up with innovative strategies to promote compliance and reduce enforcement costs. One such approach involves inviting other freeway and HOV users to report violators by calling a hotline telephone number with information about that vehicle. In Washington and several other states, such programs are named "HERO" (fig. 50). Following a call-in report of a first alleged offense, an informational brochure describing HOV rules and regulations is mailed to the vehicle's registered owner.

Upon a call-in report of a second alleged offense, letters printed on Washington State Department of Transportation letterhead are mailed out. On a third alleged offense, the vehicle owner receives a more serious warning letter from the State Patrol, and ultimately efforts are made to apprehend the violator. Because citations cannot be issued without actual confirmation of the violation by a law enforcement officer, these letters have only the power to warn.

In addition to the HERO program, other means of apprehending violators with little or no delay to the driver or officer have been developed. PHOTOCOP, for example, allows the officer to automatically "snap" a clear photo of the alleged offender. In theory, citations can then be mailed out. However, implementation may be problematic unless PHOTOCOP is installed at a location where verification of the number of passengers in the vehicle would be possible. One concern with these types of enforcement is the possible presence of small children in the vehicle, who may not be visible from the outside, leading to unwarranted citations. Therefore, a "stop and send" approach has emerged, wherein officers stop individual vehicles simply to verify occupancy. Where a violation is found, a ticket is mailed to the vehicle's registered owner. This approach has the advantage of cutting the amount of time spent writing the tickets on the spot.

TRANSIT AND THE ROLE OF TRAFFIC MANAGEMENT CENTERS

A recent editorial in the *Journal of Advanced Transport* (1995) notes a gradual shift in the focus of intelligent transportation systems (ITS) from private automobiles to public transportation (Atkins 1995). Broadly conceived, ITS encompasses advanced technologies to improve the transportation system's overall efficiency and effectiveness. Stephen Atkins, a policy manager for London Transport, suggests two primary reasons for the shift in focus to transit. First, smart car technology may not reduce traffic congestion; in fact, it could encourage even more trips and vehicle miles traveled. This possibility entails a catch, in that, "information to aid [individual] car drivers' route choices are likely to have little impact if excess demand for vehicular movement overwhelms available capacity" (Atkins 1995). Thus, the ITS endeavor must logically encompass modes with the potential to make more efficient use of system capacity.

As an example of an ITS application to transit, consider the waiting and travel time variability that often characterize transit use. This variability, and the

Figure 50. *HERO programs encourages motorists to report HOV lane violators*

Table 19. *Selected HOV Lane Violation Fines and Penalties*

State	Process for changing occupancy	Penalties
Ariz.	Arizona DOT decision	$50 by State Police Dept. of Public Safety
Calif.	All new lanes (not allowed to take general purpose lane). All at 2+ until 80% capacity then 3+. Made by Caltrans with MPO and FHWA approval	$271 & Court costs for 1st time offender; $375-400 average; Not moving violation so no license points lost
Colo.	State Trans. Comm has authority for occ. designation, taking recomm. from Traffic Engr based on vehicle counts and projections	Local control over fines and enforcement levels; roughly $35-$50 plus court costs
Conn.	Decision made by State Traffic Comm.	State police by sight. $60 for HOV designation; $78 for wrongful use of buffer area
Florida	Developing policy	$72 for violating HOV designation
Hawaii	Developing policy	State police by sight; send ticket in mail for $200 max fine.
Mass.	Developing policy	$50 for violating HOV designation
Penns.	Varies	$90 for unauthorized vehicle usage
Virginia	VADOT makes recommendations to FHWA, Congress and regional government	$50 plus $26 court costs by State Police
Wash.	When speed drops below standard of providing 45mph for 90 percent of time for a concurrent six month period	$68 moving violation by State Police

passenger's lack of control over his or her trip, are considered to be key barriers to higher levels of transit ridership. Whereas the automobile traveler has his or her vehicle immediately accessible, and needn't do much pretrip planning, the transit passenger must plan and schedule the route, transfers, and possibly layovers for the round trip in advance. If knowledge of routes, frequencies, and timings for public transportation were more readily and easily available, then at least one barrier to transit ridership would be reduced.

Indeed, improving transit information through advanced technologies is the goal of "Bellevue Smart Traveler" a project centered around interactive computer kiosks that provide real-time transit information on routes and schedules (Haselkorn et al. 1995). As Atkins observes, "...the application of information technology to collective transport is not only consistent with wider transportation policy objectives, by reducing traffic congestion and air pollution, but also is likely to be more productive than application to personal modes, when the information requirements are less crucial" (1995).

A second explanation for the ITS focus on transit lies in transit's particular suitability to ITS applications. The fact that the vast majority of transit vehicles in North America are publicly owned makes it easier to implement ITS technology and the related infrastructure. In contrast, owners of private vehicles may resist the new technologies for a variety of reasons, ranging from financial constraints to apprehension over perceived threats to privacy. In addition, transit vehicles are operated and maintained by professionals whose efforts can be coordinated.

Interest in transit applications of ITS is also reflected in a recent USDOT report that explores how to link transit with ITS through administrative structures and cooperation between traffic management and transit agencies (Schweiger 1994). The nuclei of ITS operations in metropolitan areas are transportation management centers (TMCs), examples of which include Seattle's Transportation Systems Management Center, Los Angeles's Transportation Operations Center, Minneapolis-St. Paul's Minnesota DOT Traffic Management Center/Travlink Project, and San Antonio's ITS Operations Control Center.

Motivated by the assertion that public transit has been overshadowed by the private automobile in the evolution of ITS, the report points out that "traditionally, the impact of public transportation on traffic flow and volumes has not been factored into these automatic systems." In the author's view, the lack of attention to transit is in part a function of a too clean separation between transit and traffic agencies.

However, in a few areas, such as Houston and San Antonio, TMCs and transit operations are collocated, that is, housed under one roof. Schweiger maintains that such collocation fosters better operations for both traffic and transit agencies. The benefits of integration enjoyed on the part of transit include direct access to real-time traffic information, which has the potential to make it easier for transit agencies to adjust operations dynamically. Benefits to TMCs include instantaneous notification of transit service delays, vehicle breakdowns, and schedule changes affecting general traffic flows.

As an example of integrated technologies, Schweiger considers TRANSCOM, a consortium of highway, transit, and public safety agencies in the New York metropolitan area. Ranging across portions of New York, New Jersey, and Connecticut, TRANSCOM "continuously monitors traffic conditions, construction schedules, road closings, accidents, and any incident that might disrupt the traffic on the estimated 6,000 miles of highway and 2,000 miles of track in the 500 square mile metropolitan area." Incident information is communicated by telephone, alphanumeric pager, and FAX. Technological developments initiated by TRANSCOM include variable message signs, closed-circuit TV, and highway advisory radio.

San Antonio's new ITS Operations Control Center (OCC) is another example of well integrated traffic and transit operations. This new facility will eventually manage 191 miles of roadway. Overseen by the TXDOT, the OCC houses not only DOT personnel, but local law enforcement and VIA, the metropolitan area's transit agency. VIA received an FTA grant to tie its dispatching operations into the fiber-optic network installed as part of the OCC.

The San Antonio OCC is the fruit of the TXDOT's careful cultivation of interagency cooperation. A first step in project planning was to build consensus among local agencies and authorities in an existing corridor management coalition. This coalition included representatives of local law enforcement, emergency services, city and county governments, and transit.

Schweiger takes the collocation she found in these areas as an indication that collocation is both feasible and worthwhile. However, she concedes that it may not always be feasible to collocate transit and TMCs, for reasons including, but not limited to cost, institutional issues, and politics. She thus offers strategies for pursuing integration on a more limited scale. These strategies involve setting small, manageable goals; assuring all agencies that their roles and responsibilities can remain the same even as they work together more closely; and recognizing the value of interagency agreements in establishing expectations and boundaries at the outset.

CONCLUSION

In producing this report, the authors have sought to compile, from a transit-centered perpective, a wide range of information and resources pertaining to the sorts of strategies, facilities, policies, and operations that constitute the HOV domain.

Essentially, the task has been to describe current HOV operations—on arterials and freeways—and to consider how such facilities can be designed and operated in such a way that transit can work most efficiently. It is hoped that others will find this report, along with its extensive bibliography, useful in developing their own transit and HOV strategies.

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C R E D I T S

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