4 Bus Facilities on Limited Access Highways

In This Chapter:

Bus service on freeways and other limited-access highways continues to increase. That growth reflects the expansion of downtown and suburban oriented markets, the growth of HOV lanes, the development of bus-only roadways, and the emergence of bus rapid transit. Bus operation on freeways improves operating speeds and service reliability, especially where priority or exclusive facilities are provided.

Providing separate facilities for buses and other high-occupancy vehicles (HOVs) can be a cost-effective means of improving person capacity within a corridor. The use of freeway rights-of-way usually results in lower land costs than for two separate facilities, reduces the displacement of businesses and residences, and lessens impact on neighborhoods.

This chapter addresses bus facilities built within a controlled access highway environment, including special lane treatments for bus priorities, bus access facilities, and passenger transfer facilities within the freeway environment.

The chapter begins by discussing general policy considerations such as eligibility, need and justification, and broad design guidelines. It then describes the various lane configurations and geometric guidelines for each type of treatment; provides guidelines for access into and out of busways, bus lanes, and HOV lanes; presents treatments for stations and stops; discusses operational requirements such as signing and enforcement; and addresses the desirability of protecting rights-of-way for the future. The focus is on bus-only facilities. However, since buses operate in HOV (or "managed") lanes on many freeways, design requirements for these facilities are also included.

4.1 GENERAL PLANNING AND DESIGN CONSIDERATIONS

4.1.1 Freeway Bus Service Types and Functional Requirements

Transit operation on freeways includes a broad range of express, limited stop, and intercity services. Some services operate all day; others run only during peak periods. Some routes may operate non-stop, whereas others may make intermediate stops to serve intersecting local bus routes, park-and-ride facilities, or adjacent developments.

A sound understanding of existing and potential bus routes, patterns of passenger demand, levels of ridership, and service delivery strategies is a prerequisite for developing transit infrastructure and design requirements.

4.1.2 Policy Context

When buses operate with other traffic, the operating and enforcement decisions made by roadway engineers can influence the speed, reliability, and safety of transit services. A collaborative decision-making approach for transit (and carpool) operating, design, and enforcement policies is essential, especially on HOV, high-occupancy toll (HOT), and managed lane facilities that seek to maintain transit speed and reliability through congested freeway segments.

Transit (and carpool) agencies often work closely with their respective state department of transportation in each phase of facility development. Collaborative decisions also create a broader constituency for transit- and HOV-oriented policies that can provide broader support when transit-supportive freeway policies are adopted. Policies can involve preservation of right-of-way for future improvements or integrated facility development within the roadway, often implemented as part of an overall road/transit improvement involving the same construction activities.

4.1.3 Selecting the Appropriate Facilities

Transit vehicles operating in urban environments often are subject to delay caused by traffic congestion. Congestion results in longer travel times for passengers and may require transit agencies to add more buses to routes to maintain headways, which results in increased operating costs. (*1*)

Preferential lane treatments for buses are implemented to reduce delays and improve reliability for transit operating in congested, mixed traffic. Fast and reliable services may also attract new riders, increase transit capacity in a corridor, and improve the quality of transit services for passengers.

According to the *Transit Capacity and Quality of Service Manual (2nd Edition),* bus preferential treatments generally can be defined as a range of techniques designed to improve transit vehicle travel speeds and improve overall system of efficiency. (*15*) Types of treatments include dedicated lanes operated as bus only or bus with other HOVs. These treatments may reduce travel time variability and improve schedule adherence for transit. The total person-delay (including passengers in both buses and private vehicles) should be considered when implementing a project to provide dedicated lanes for buses. Facilities should be cost-effective, and planners should consider both the long-term changes to mode split and the potential for attracting new users. Dedicated lanes are more acceptable to policy makers and the community when they do not create undue traffic disruptions to the general-purpose lanes.

Buses operating along freeways may operate in bus-only roadways (busways) or in bus-only lanes or designated shoulders. Busways permit high speed, good adherence to schedule, and high visibility, which are desirable for bus rapid transit service. Bus-only lanes or shoulders along freeways improve bus service performance at a lower cost than a dedicated busway.

HOV lanes and segregated bus roadways also improve bus speeds and reliability. Throughput is increased, particularly when dedicated lanes carry a large number of passengers. Barrier-separated HOV lanes usually require larger cross-sections than bus-only facilities. Sometimes, bus/HOV lanes function as elongated queue bypasses. Table 4-1 lists the types of preferential treatments for buses on limited access highways and provides the advantages and disadvantages of each type of treatment.

4.1.4 General Guidelines

Two basic objectives underlie providing bus transit facilities on limited access highways:

- Bus facilities should contribute to improved person throughput.
- Bus facilities should be integrated into the corridor.

Table 4-1. Types of Preferential Treatments for Buses on Limited Access Highways (*1*)

Treatment	Advantages	Disadvantages
Exclusive busways	• Increase bus speed by reducing sources of delay • Improve schedule reliability • Increase transit identity and visibility	• Difficulty obtaining sufficient right-of-way in existing or new corridor • Cost to construct
Freeway bus lanes	Same advantages as exclusive busway; however, benefits may not be as significant: • Increase bus speed • Improve schedule reliability • May increase transit visibility	• Adverse effects on traffic, if created by eliminating an existing travel lane • Cost to provide new capacity • Requires provisions for preferential access
Freeway HOV lanes	• Improve operating speeds for transit users, carpool, and vanpool users • Improve schedule reliability • Increase person movement capacity of roadway	• Adverse effects on traffic, if created by eliminating an existing travel lane • Cost to provide new capacity • Requires ongoing enforcement • May pose safety problems for vehicles entering and leaving the lanes unless physically separated
Managed or express lanes with preferential access for transit	• Improve transit operating speed • Improve schedule reliability	• Requires a policy commitment to prioritizing transit as an objective of the managed lane operation
Bus only or priority ramps	• Maximizes the benefits of bus lanes or HOV lanes by removing delays for access	• Cost to construct • Requires ongoing enforcement
Queue bypass	• Reduces delay for queues at ramp meters or other locations	• Bus or HOV lane must be available • HOV preferential treatment requires ongoing enforcement

Additional key considerations include the following:

- It is important to identify existing and anticipated congested areas. Generally, dedicated lanes should save at least 30 seconds per mile compared to travel in general purpose lanes.
- It is not feasible to remove general purpose travel lanes in the heavy direction of travel for use by transit (and HOVs). Priority facilities should be implemented through added lanes.
- Standardization of freeway entrance and exit points to the right of the through traffic makes the use of median priority lanes feasible.
- Metering of freeway ramps with bus (or HOV) bypass lanes can improve mainline freeway flow and reduce delays to buses/HOVs.
- Radial freeways in urban areas that exceed one million population (especially two million) are good candidates for providing reservation for transit (or HOV) either within the median or alongside major roadway facilities.
- Where bus rapid transit service is planned along freeways, building stations along the dedicated lanes can improve the speed, reliability, identity, and passenger attractiveness of the service. These are commonly referred to as on-line or in-line stations.
- Where right-of-way is limited, bus use of shoulders should be considered for congested highway facilities.

Tables 4-2 and 4-3 provide some general design guidelines for transit lanes on limited access highways. Preferential lane treatments should be considered when the following criteria are met:

Table 4-2. General Guidelines for Dedicated Lanes for Buses on Limited Access Highways

Bus Only Treatment	Minimum Bus Volume*	Minimum Passenger Volume*	Related Factors to Consider
Exclusive busway (separate right-of-way)	40–60	1,600–2,400	• Urban operating environment with major employment center destination (usually with more than 50,000 jobs) • Congestion in corridor
Exclusive busway within freeway right-of-way	40–60	1,600–2,400	• Freeway experiences severe peak-hour traffic congestion
Freeway bus lanes, normal flow	60–90	2,400–3,600	• Bus passenger time savings should exceed other freeway user delays • Often provided by adding a freeway lane
Freeway bus lanes, contraflow (borrowed lane)	40–60	1,600–2,400	• Freeways with six or more lanes • Imbalance in traffic volume permits freeway LOS D in off-peak travel direction
Bus-only or priority ramps	10–15	400–600	• Passenger travel-time savings should be significant to warrant capital investment for exclusive access
Bus bypass lane at ramp	10–15	400–600	• Savings up to 90 percent of ramp meter delay

* Peak hour, one-way—design year. Should be 75 percent of these values in base year.

Table 4-3. General Guidelines for HOV Lanes on Limited Access Highways (*1, 2, 14*)

HOV Treatment	Minimum HOV Vehicle Volumea,b	Minimum HOV User Volume[a,b,c]	Related Factors to Consider
HOV, separate right-of-way	800–1,000	3,100–4,300	• Travel-time savings up to 20 percent
HOV, freeway	400–800	1,600–3,100	• Travel-time improvements are a function of existing delays on freeway
Queue bypass	100–200	400–800	• Savings up to 90 percent of ramp meter delay

[a] Peak hour, one-way—design year. Should be 75 percent of these values in base year.

[b] HOV includes bus, car, and vanpool vehicles.

[c] HOV users include HOV drivers, passengers, and bus passengers.

- Traffic congestion is significant and causes delays in scheduled transit service.
- The bus/HOV lane will result in travel time savings for transit passengers (typically preferential treatment should save at least one minute per mile).
- A sufficient number of buses will use the dedicated lane, resulting in increased person throughput. (*14*)
- Physical roadway characteristics and the roadway geometry are suitable.
- Design options for implementation are cost-effective.
- Transit operations will not create undue traffic disruptions for the general-purpose lanes.
- Traffic lane is enforceable.
- The community is supportive.
- Public policy encourages transit, and local public agencies will support operating regulations and provide necessary funding.

4.2 TREATMENTS

This section provides a description and design guidelines for buses operating along freeways in general traffic lanes, HOV and managed lanes, and bus-only lanes. HOV lanes typically limit use to buses, carpools, and vanpools, while managed lanes permit general traffic, which typically is tolled use when space permits.

Lane types may take various forms such as median or shoulder alignments. They may be concurrent flow or barrier-separated and operate part-time or full-time. Buses also may operate in separate bus-only roadways within, or adjacent to, a freeway corridor. (See Appendix D for more information.) This section discusses bus (or HOV) bypass lanes at metered freeway entrance ramps, direct HOV-only or bus-only access/egress ramps, and various transition treatments.

Three terms are applied to the various types of designs presented: desirable, reduced, and minimum. In every instance desirable designs are recommended for new facility applications in new rights-of-way or as part of major reconstruction of existing roadway facilities. Reduced designs may be acceptable on a

case-by-case situation where the bus/HOV facility would not otherwise be feasible to implement because of such constraints as limited right-of-way. Minimum guidance reflects a condition that should exist only at a spot location or in isolation on an otherwise desirable or reduced design, where all other options to preserve a better design have been explored. All design settings have documented experiences in the United States.

4.2.1 Lane Treatment Design Considerations and Cross Sections

The same geometric standards apply to HOV, managed lanes, and, in most cases, bus-only facilities.

Concurrent-Flow Median Lanes

Concurrent-flow dedicated bus/HOV/managed lanes are dedicated lanes operating in the same direction of travel as adjacent general purpose lanes. They are not physically separated from the general purpose traffic lanes and are designated for exclusive use by buses and eligible vehicles for all or part of the day. Left-side lanes adjacent to the median are the most common application for transit priority infreeway settings in North America and represent more than two-thirds of all dedicated HOV-lane mileage in 2005.

Dedicated lanes often are developed by retrofitting a freeway cross-section within the right-of-way. For example, the inside shoulder of a freeway median may be converted to an additional lane, or the freeway and right-of-way may be expanded to create lanes next to the median.

Pavement markings normally separate the dedicated lanes from other traffic. Specific access points placed every several miles should be provided, although in many places unrestricted access is permitted. Because there may be a high-speed differential between the general purpose lanes and the concurrent-flow lane, unrestricted access may introduce a safety concern in high-weaving locations. Conversely, designating access may inordinately congest these locations.

The median (left) lane normally is preferred because it is removed from conflicts with entering and exiting traffic. However, a right-side dedicated lane designed primarily for buses may be appropriate in special circumstances, such as between successive on- and off-ramps.

Lane and Shoulder Widths

The desirable cross section for a concurrent-flow lane on the median side includes a full-width breakdown shoulder (Figure 4-1). AASHTO identifies a shoulder width of 3.0 to 4.2 m (10 to 14 ft) as desirable next to the median barrier. Many projects employ narrower designs because of design constraints. The use of narrow shoulders or limited lateral clearances next to a median barrier needs careful examination on a project-by-project basis and may be approved for only a limited time. (*2*)

Enforcement of HOV lanes is important to their success. Provision of enforcement shoulders requires added right-of-way, but this investment is valuable. Enforcement shoulders may not be necessary along the entire length of a dedicated lane, but rather, at key enforcement locations.

Concurrent-Flow Right-Side Lanes

Dedicated bus/HOV lanes sometimes are located in the outside lane or on a designated outside shoulder or lane. In those cases, conflicts may occur with freeway on- and off-ramps. They generally are limited to locations where transit only or 3+ passenger occupancy use is justified for low volumes. There are few conflicting ramps, and the conflicting volumes at ramps are relatively low. The dedicated lanes

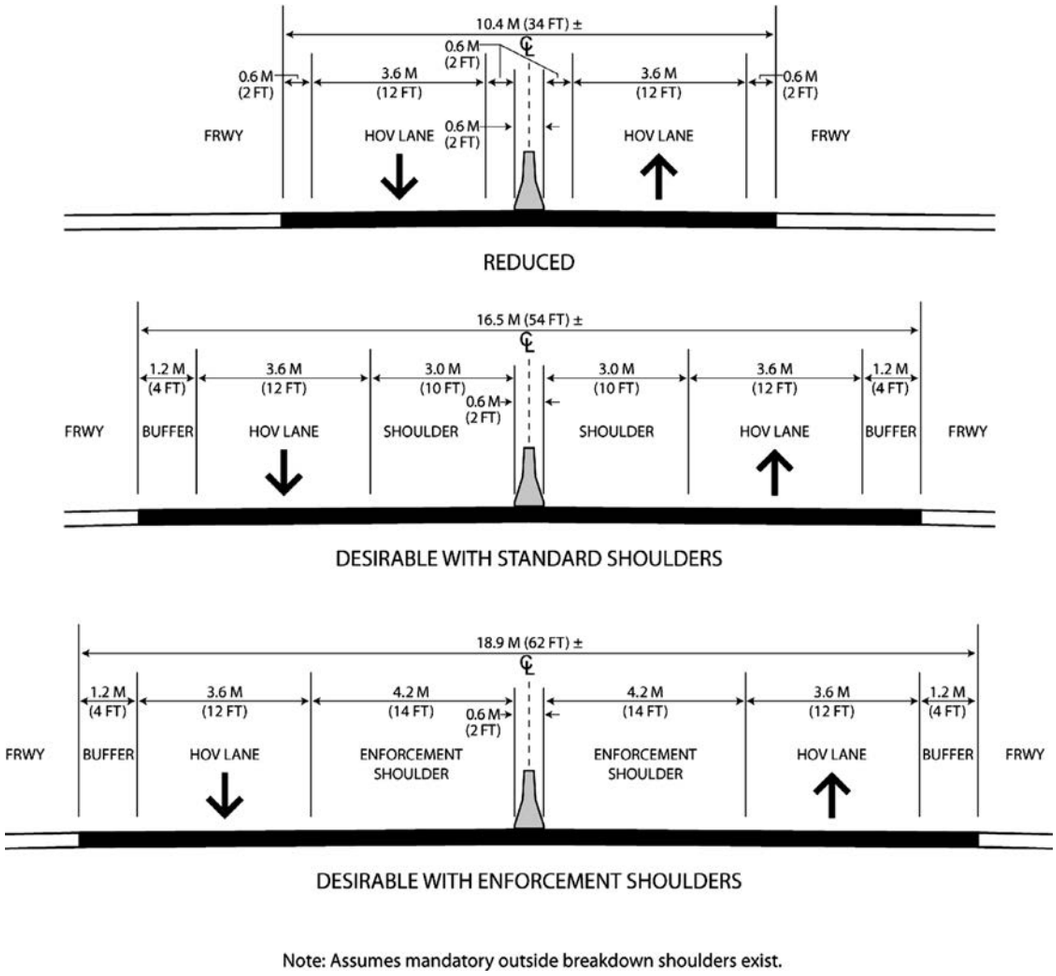


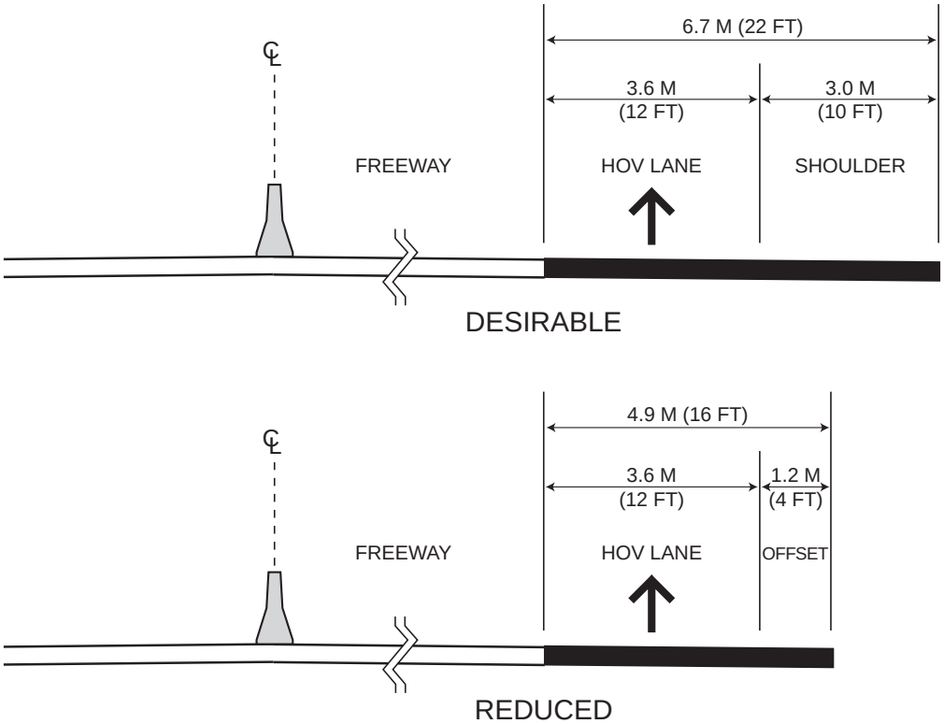
Figure 4-1. Typical Cross Sections for Concurrent-Flow Buffer Separated Lanes (*12*)

on SR 520 in Bellevue, Washington, are an example of this type of treatment. In Ottawa, Canada, the shoulder bus-only lanes are an extension of the East–West Transitway. Buses avoid conflicts at ramps by either merging with general through traffic or exiting the freeway to an off-line bus stop at the crossing road and re-entering the right lane from the freeway entry ramp. In Minneapolis–St. Paul, buses operate on freeway shoulders at a prescribed speed in a queue-jump mode, but only when congestion levels dictate.

Figure 4-2 illustrates cross sections for a concurrent HOV lane on the outside of a freeway. A paint stripe is the normal way to separate it from the general-purpose traffic lanes. Since the outside shoulder may be borrowed for the bus/HOV lane, the remaining shoulder may be very narrow one, or absent.

Barrier-Separated Lanes

Barrier-separated bus/HOV lanes within freeway medians may provide one or multiple lanes. Barriered facilities typically operate with one or more lanes in each direction, or one-way inbound during the



Note: Reduced cross-section assumes part-time peak period use, with bus/HOV lane reverting to shoulder use at other times.

Figure 4-2. Typical Cross-Section for Concurrent Flow Right Side Lanes (*12*)

morning hours and outbound during the evening. From a bus transit operations perspective, two-way lanes are preferable since they enable buses to run each way at all times and to deadhead without encountering off-peak direction congestion.

Both types of lanes are separated from the adjacent general purpose freeway lanes by concrete barriers. The barrier separation limits the frequency of direct access. Access may include slip ramps or fly-over ramps to and from adjacent lanes or other intersecting roadways and transit facilities.

A barrier should separate the opposing flow traffic in a two-way operation (Figure 4-3). However, the barriers are not essential if the lanes are used only by buses, since only professional drivers would use the lane. In such a case, a 0.3- to 0.6-m (1- to 2-ft) painted buffer stripe may suffice.

Reversible lanes, typically located within the freeway median, are always physically separated from the general-purpose freeway lanes. The lanes should be gated and operated directionally—typically inbound toward the central business district (CBD) in the morning and outbound in the afternoon. Daily set-up is required with reversible facilities, which often include opening gates to the lanes in the morning, closing the lanes to inbound traffic, reopening the lanes in the reverse direction of travel in the afternoon, and closing the lanes in the evening. Usually a combination of manual and automated

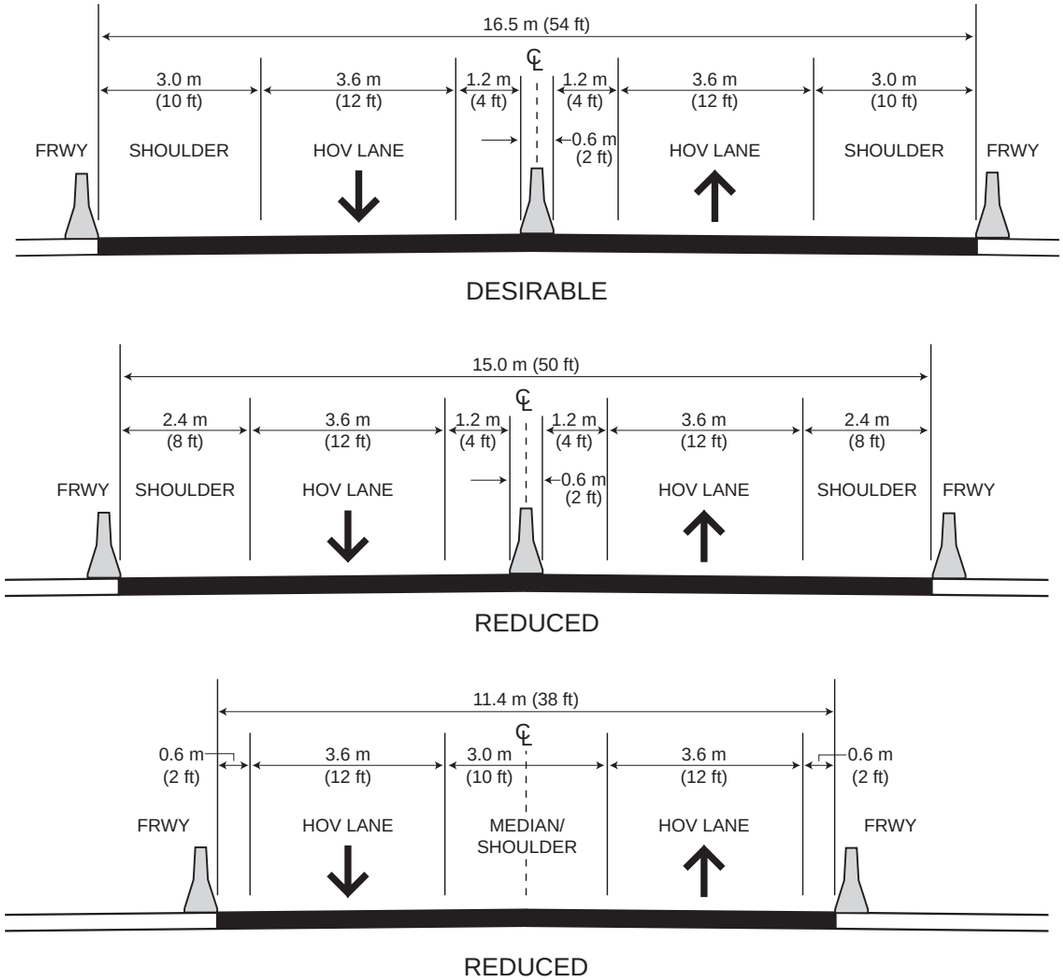


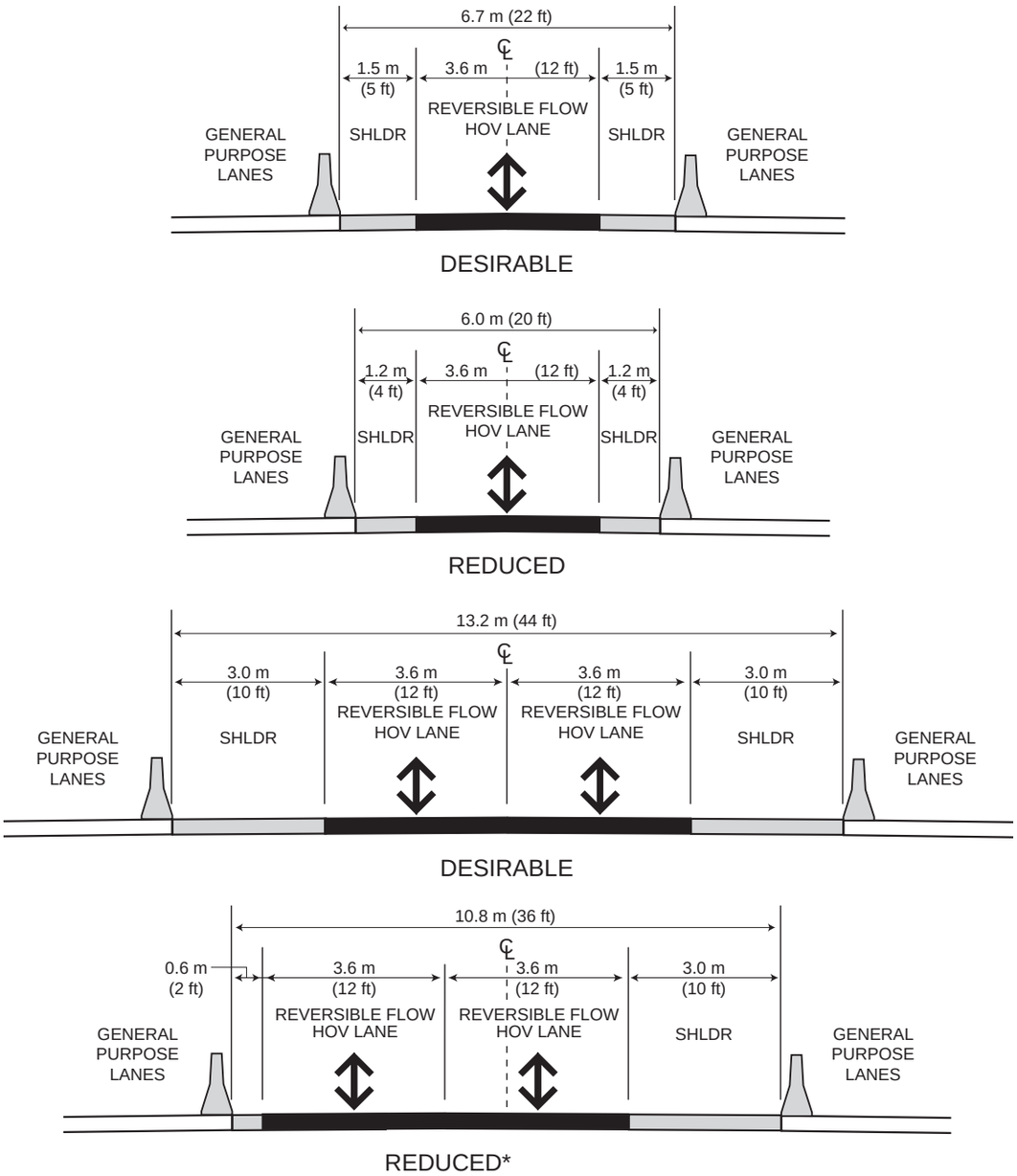
Figure 4-3. Typical Cross Sections for Two-Way Barrier-Separated Lanes (*8, 12*)

techniques is used to open and close reversible lanes, since some field intervention is needed to assure safe operation.

Barrier-separated reversible lanes (Figure 4-4) are in operation in the Houston, Dallas, Minneapolis, Seattle, San Diego, Pittsburgh, Denver, Norfolk, and northern Virginia areas.

Busways and HOV Roads on Separate Rights-of-Way

Bus-only roads (busways) or HOV roads can be provided on separate rights-of-way, either alongside freeways or in independent corridors. The cross section of a busway consists of the lanes, shoulders, and any necessary roadside areas. Figure 4-5 illustrates desirable and reduced design widths for cross-section components. The reduced configuration is not applicable along roadways operating at highway speed because of safety concerns, but it may be appropriate where speeds are equivalent to arterial operation. Appendix D gives further information on busways.

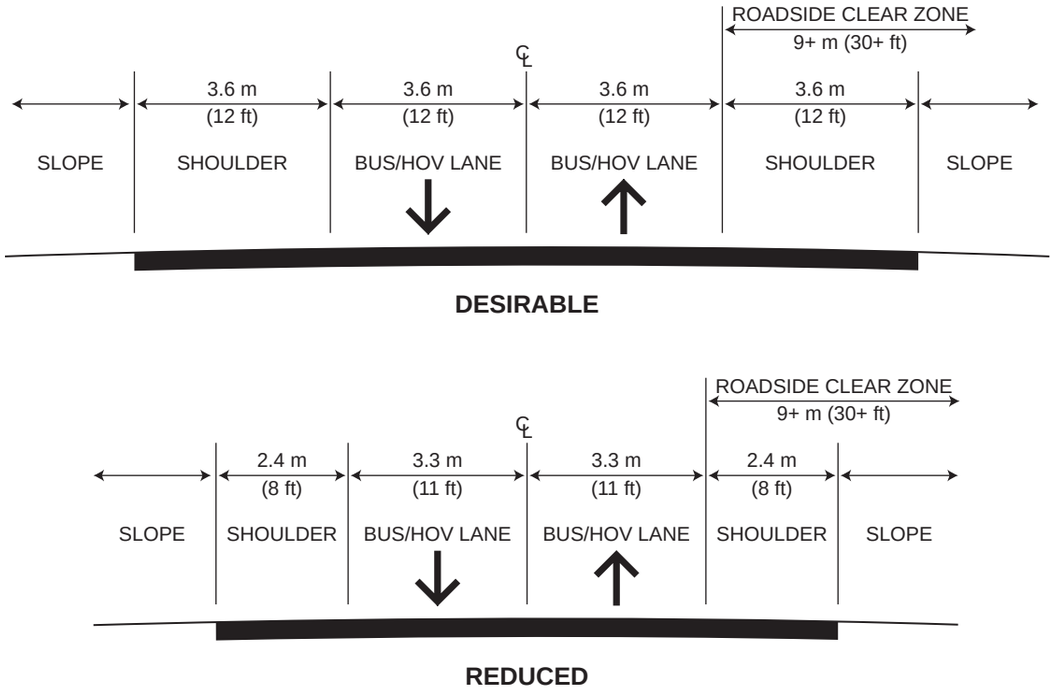


*Operational treatments should be incorporated if the minimum design cross section is used. the minimum cross section should be used as an iterim project or over short distances. Increased enforcement and incident management programs should be implemented to successfully operate the facility.

Figure 4-4. Typical Cross Sections for Reversible Lanes (*12*)

Contraflow Lanes

Contraflow operations borrow a general-purpose lane from the off-peak direction of travel for use by buses and possibly other HOVs operating in the peak direction. They should be considered only where there is a high directional traffic split. Capacity exists in the off-peak direction of travel to borrow a lane or lanes without adversely affecting traffic conditions, and where the dedicated lane can be designed and operated safely.



Note: For busways, paved shoulders may be reduced to as little as 0.6 m (2 ft).

Figure 4-5. Typical Cross Sections for Busway or HOV Facility in Separate Rights-of-Way (*12*)

Since contraflow lane facilities involve traffic operating in opposing directions on the same side of a freeway, safety for both transit and general-purpose traffic is key in the design process and involves employment of some type of physical separation. Separation typically involves the application of pylon placement or movable concrete barriers. Most such treatments now employ movable barriers to improve operation safety between opposing traffic flows.

Six contraflow bus/HOV lanes were in operation on freeways in the United States in 2005. The Route 495 bus-only contraflow lane in the New York City/New Jersey area uses plastic pylons inserted into holes in the pavement to separate the traffic lanes. Most other facilities, such as those on the Long Island Expressway in New York City, East R. L. Thornton Freeway (I-30 East) in Dallas, Gowanus Expressway in New York, (dual bus-carpool lanes) Highway H-1 in Honolulu, and the Southeast Expressway in Boston, use a movable barrier to separate the contraflow lane. The a.m. peak period contraflow lane on the approach to the Lincoln Tunnel has a special access ramp on the west end, connects to a bus-only lane through the Lincoln Tunnel, and transitions to bus-only ramps leading to the Midtown Bus Terminal in Manhattan. The lane is typically 3.0 m (10 ft) wide along most of its length. It carries about 700 buses during the peak hours and has performed safely since 1969.

Figure 4-6 shows cross sections for contraflow HOV lane facilities using both types of treatments.

4.2.2 Access Treatments for Bus/HOV Lanes

Access to most bus/HOV lanes is at designated locations. Each access configuration needs consideration in handling its beginning and end treatments. The type of access provided will depend on the type of

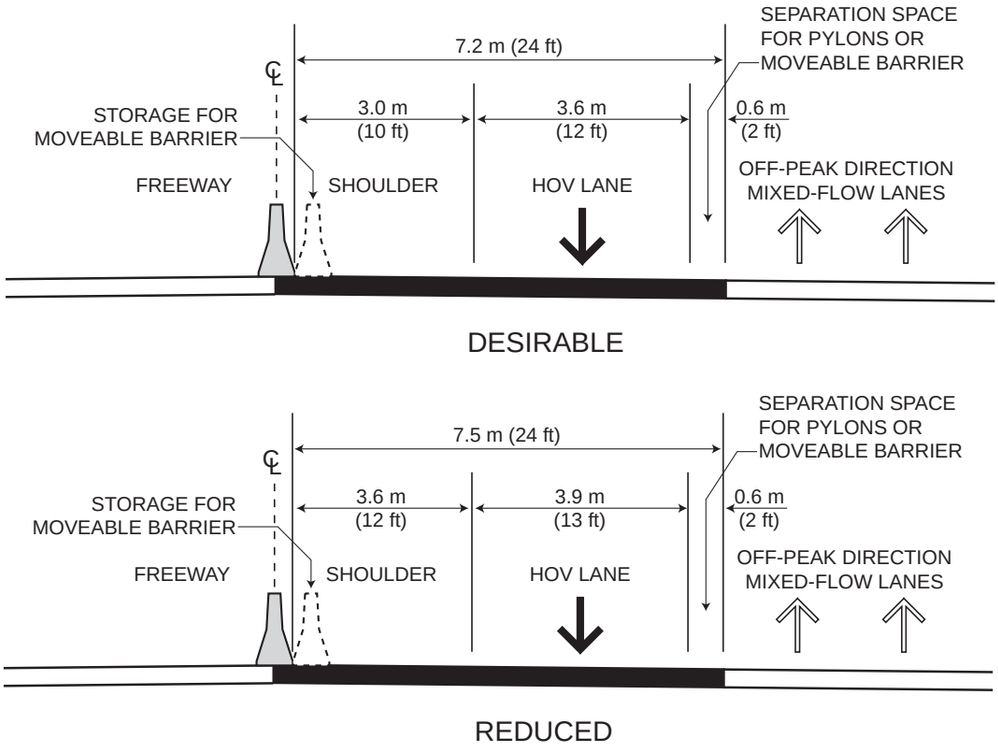


Figure 4-6. Typical Cross Sections for Contraflow Lanes (*12*)

facility, the roadways it crosses, land uses in the corridor, available rights-of-way, funding capabilities, and, most importantly, where transit services originate and depart the roadway. Facilities may connect directly with bus-only lanes or on city streets, bus terminals, and major park-and-ride facilities. See the *HOV Systems Manual* (NCHRP Report 414) for additional guidance (*12*).

Metered Bus and HOV Ramps

Metering the use of freeway entrance ramps gives buses and HOVs priority. Metering can improve the overall freeway level-of-service and reduce accident rates by regulating the flow of traffic and by dispersing platoons of vehicles that typically enter freeways during the peak periods. Ramp metering could discourage drivers from using a freeway for local trips more easily made on the arterial street system.

Providing buses (and other HOVs) with a way to bypass the queues that form upstream of ramp meters, especially during the peak-hours, can reduce delays and improve route reliability. These treatments can be implemented independently or in conjunction with priority freeway treatments.

Two design approaches usually are applied for transit bypass lanes at metered freeway entrance ramps: (1) providing an additional transit bypass lane as part of an existing ramp, and (2) providing a separate transit ramp usually located downstream of the metered ramp. The first is more common. Figures 4-7 and 4-8 depict these layouts. Provisions for enforcement are desirable where space permits.

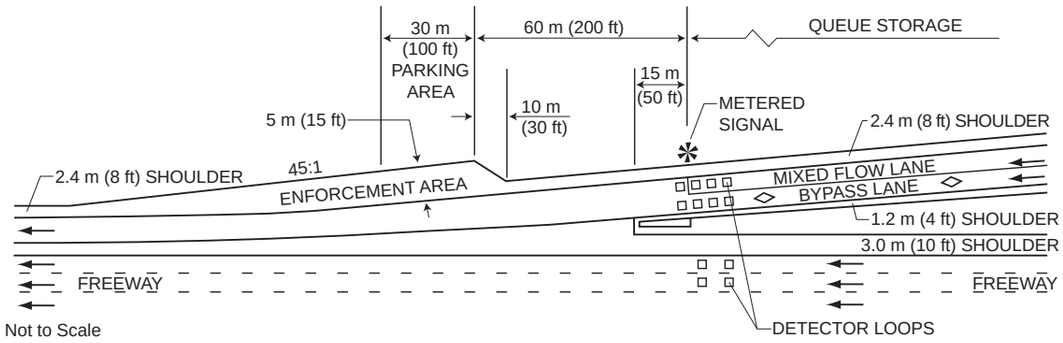


Figure 4-7. Typical Layout for a Bus/HOV Bypass at a Metered Freeway Entrance Ramp (*12*)

Direct Access Ramps

Grade-separated or direct access ramps can provide effective dedicated ingress and egress for buses and HOVs where high passenger and vehicle volumes are expected or where additional time savings and operational efficiencies can be gained. Various design treatments may be used to provide a direct access ramp. Direct access typically is provided to serve major passenger traffic generators or to connect with major park-and-ride lots and off-line transit stations. The ramps may be used anywhere along the facility. Direct connections make it possible to move high passenger volumes into and out of a bus facility, but their disadvantages can include need for additional right-of-way, the capital costs associated with such ramps, and deviations of certain transit routes.

Various common ramp alignments can be implemented. The exact design will depend on the operation and design of the bus/HOV facility, its location within the adjacent freeway, available rights-of-way, intersecting roadway patterns and national and local design practices. Figure 4-9 shows an example of ramps to and from a two-way bus/HOV operation.

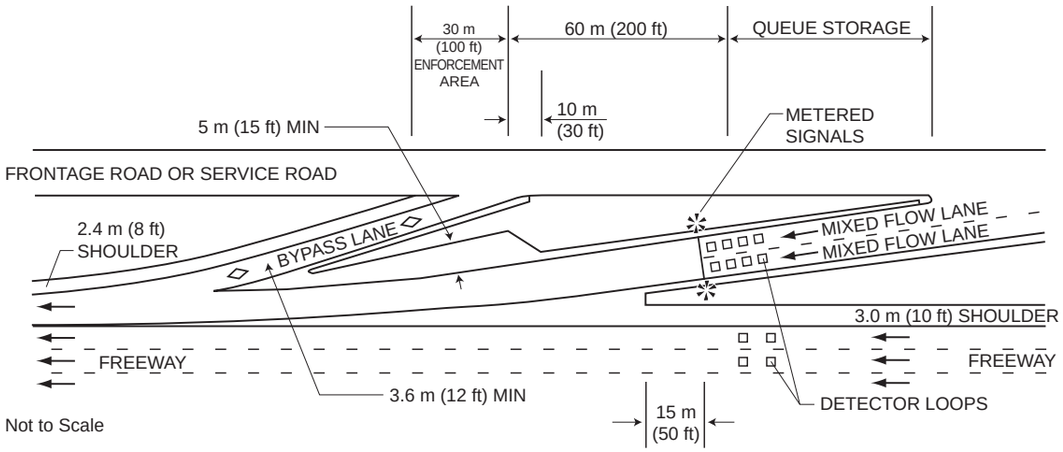


Figure 4-8. Typical Layout for a Separate Bus/HOV Bypass on a Metered Freeway (*12*)

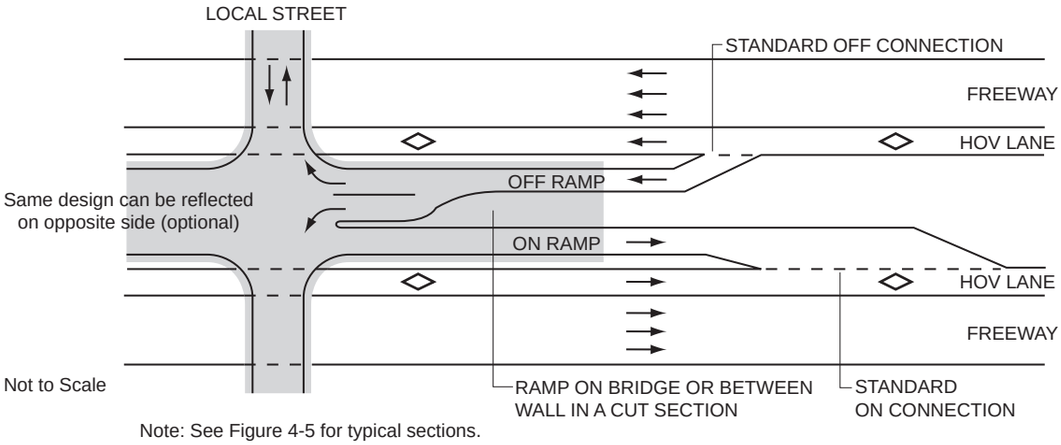


Figure 4-9. Example of a Bus/HOV Drop Ramp (*16*)

Terminal/Beginning Treatments

The design of the beginning and end of a bus (or HOV) facility is important for several reasons. First, the design should allow vehicles to enter and exit the facility easily and safely. The design should be clear and understandable, especially where carpoolers and vanpoolers enter and leave the dedicated lane. Second, the terminal treatments should provide a safe means for users to merge into and out of general traffic lanes. Third, the beginning and end of a bus/HOV facility should not adversely affect the operation of the general-purpose freeway lanes, or traffic flow on interchange roads and streets.

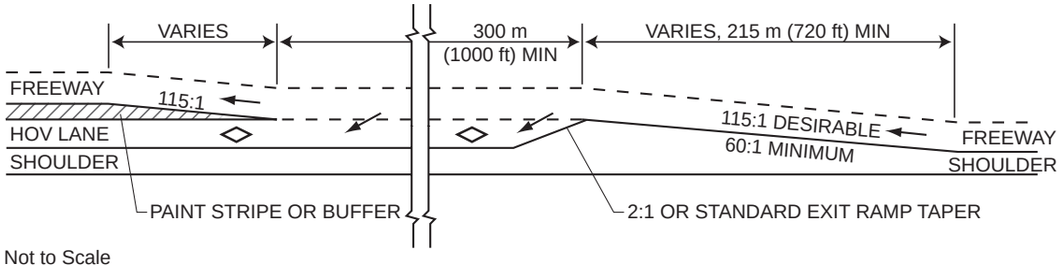
The terminal treatments may include connections to the main freeway lanes or to intersecting roadways. Designs should provide adequate transition distances for acceleration, deceleration, and merging. Where the bus (or HOV) facility joins city streets, adequate storage distances and traffic signal controls should be provided.

Lane Entrances. The entry point usually is on the left side of the facility or on a direct access ramp. The design of the entrance will depend on the type of lane and local conditions. Figure 4-10 provides examples of the two basic entry treatments for a barrier-separated and non-barrier-separated lane.

Lane Exits. The end of a dedicated lane should be designed to enable buses and HOVs to safely merge back into the general-purpose freeway lanes without causing congestion. Wherever bus/HOV lanes experience high volumes, another approach is to end the lane restriction and to continue the lane downstream of the project's termination and drop the right general-purpose lane beyond at a downstream interchange. Figure 4-11 shows examples of layouts for end treatments for a lane-drop condition.

Intermediate Access

Direct merge or at-grade access represents the most commonly used intermediate treatment with concurrent flow bus/HOV lanes. Two types of approaches are used in North America: unrestricted or unlimited access and restricted or limited access. Unrestricted access usually is used with bus/HOV facilities that operate only during the peak periods. This approach allows the bus/HOV lane to revert easily to a general-purpose lane at other times. Restricted access is used when priority lanes operate at all times.



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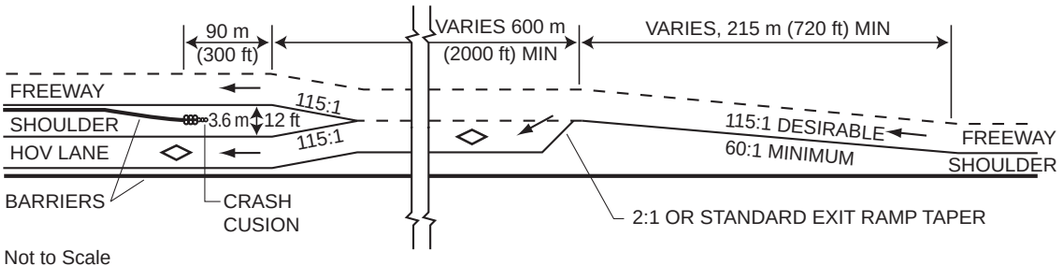
EXAMPLE OF ENTRANCE TO CONCURRENT FLOW BUS OR HOV LANE



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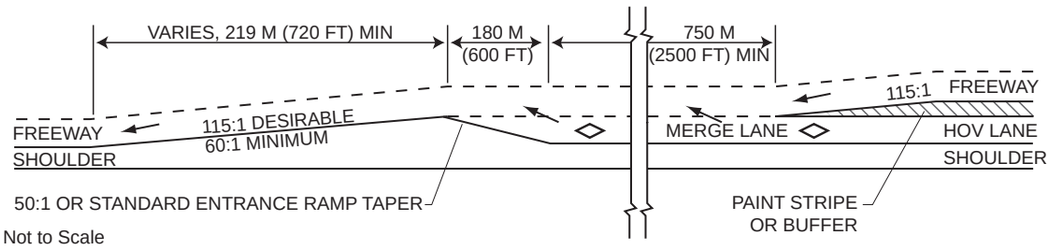
EXAMPLE OF ENTRANCE TO BARRIER-SEPARATED BUS OR HOV LANE

Note: dimensions shown are minimum.

Figure 4-10. Typical Layouts for Bus/HOV Lane Entrance (*12*)



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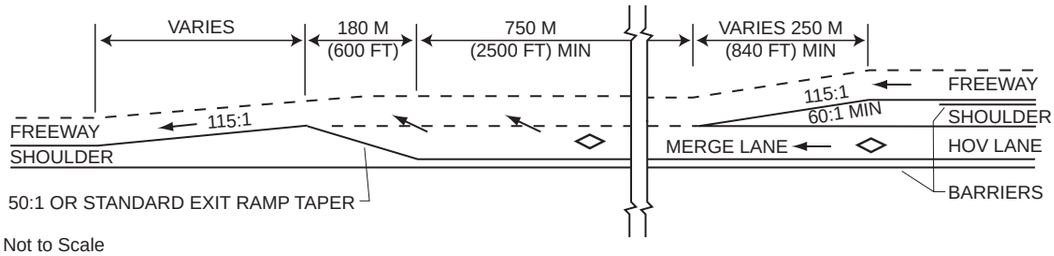
TERMINATION FROM BUFFER-SEPARATED LANE



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TERMINATION FROM BARRIER-SEPARATED LANE

Figure 4-11. Typical Layouts for Bus/HOV Lane Termination (*12*)

Where access is restricted, a relatively inexpensive intermediate access treatment is the use of slip ramps. Slip ramps may be used with barrier-separated or buffer-separated lanes. Slip ramps provide a break in the barrier or buffer, allowing HOVs to enter or exit the facility. Most slip ramps represent a break in the buffer delineation and allow ingress and egress. For higher volume locations, slip ramps can be provided with weave lanes. Potential safety issues should be examined in the design. Figure 4-12 provides layouts for this type of access treatment.

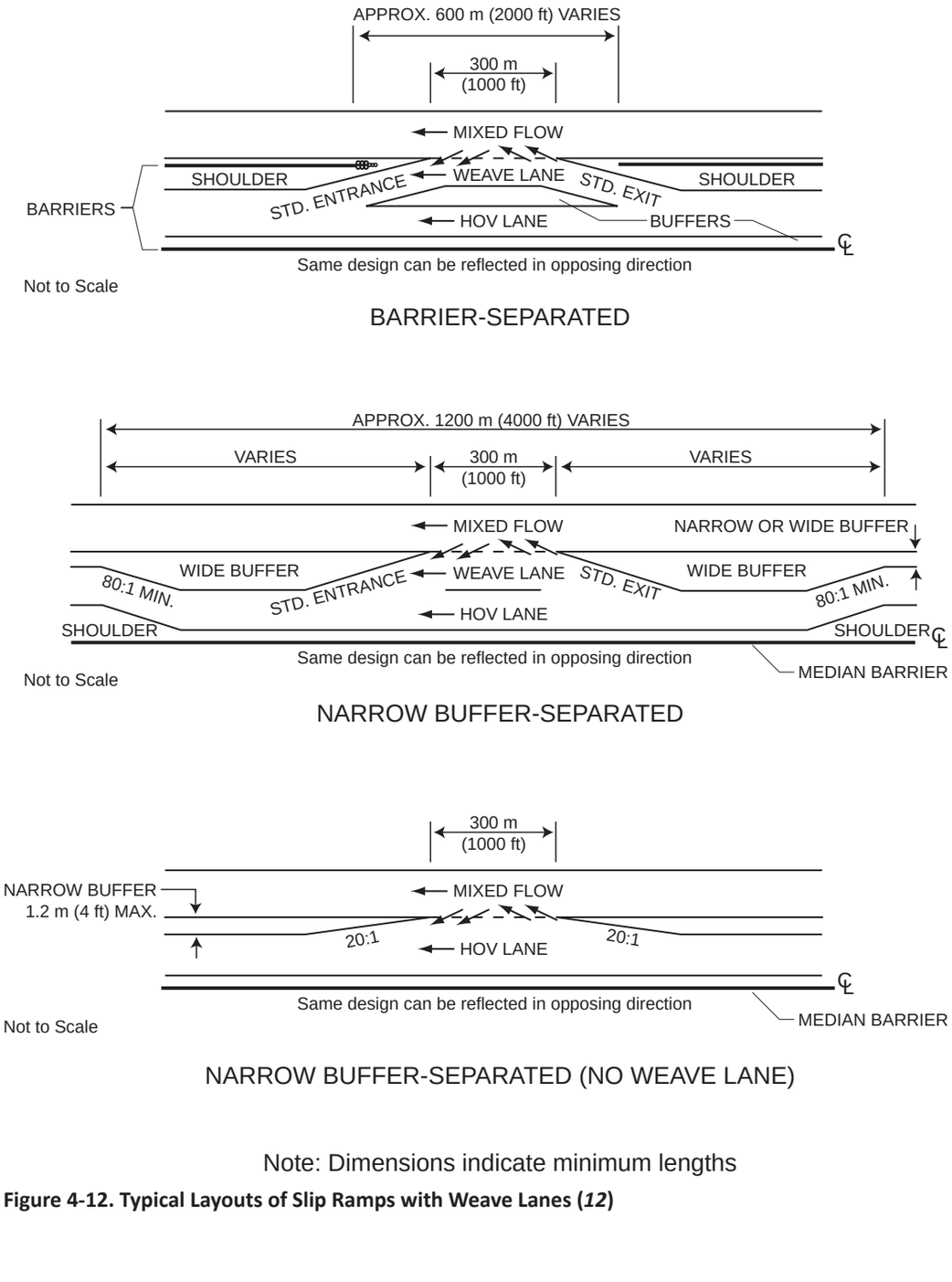


Figure 4-12. Typical Layouts of Slip Ramps with Weave Lanes (*12*)

4.2.3 Stops and Stations

General Considerations

Bus stops and stations along or adjacent to limited access highways are essential components of freeway bus systems. Transit stops and stations provide a means for transit passengers to transfer between different bus routes and services. For example, passengers can transfer from bus rapid transit limited-stop and express buses to connecting local routes, including special routes that may serve as circulators through an employment area or passengers may access the station by walking, bicycling, driving, feeder bus, or being dropped off. They can also establish an identity for bus services, which is especially important for bus rapid transit operations.

Transit passenger facilities are vital to the transit operational design. The ability to create and operate bus passenger facilities that are easily accessed; that are safe, attractive, and comfortable to users; and that do not disrupt the safe and efficient operation of general traffic is key to effective bus use of highways. Several issues influence the location and siting of passenger facilities. Frequency and service type are key factors.

Buses operating with short headways and frequent pick-up and discharge points are likely to accumulate at stops. This condition should be accommodated in stop design to minimize interferences to through traffic. Alternatively, express buses with few or no stops along the freeway provide fast transit service to outer urban areas and affect freeway operations the least. Both types of services can be provided along a given bus stop location and spacing.

Bus Stop Location and Spacing

Bus stops should be placed in areas of high passenger attraction, at interchanging road and bus lines, and near major park-and-ride facilities. Their spacing generally should reflect population densities, with wider spacing in suburban areas, where most passengers arrive and depart by personal vehicle.

Wide station spacing is desirable to enable express buses to operate at high speeds. A spacing of at least 3.5 km (2 mi) between stops permits buses to operate at or near prevailing general traffic speeds. Closer spacing of 1.0 to 2.0 km (0.6 to 1.2 mi) normally is provided to give passengers access to interchanging streets and bus lines. Since all buses do not have to stop at all stations, spacing can be closer than those used by rail transit lines.

Bus Stop Arrangements

Bus stops may be provided along the freeway, which requires stairs, ramps, escalators, or elevators; or at the street level, which requires bus access on interchange ramps. If possible, bus stops should be located where site conditions are favorable and where gradients on acceleration lanes are flat or downward.

Bus stops located at the freeway level require little additional bus schedule time other than for stopping, loading, and starting. They provide a sense of "identity" to the bus service, especially where bus-only lanes or busways are provided. However, turnouts, stairways, or extra spans at stations may be needed.

Where bus rapid transit is provided along freeways, stops generally should be located at the freeway level. Bus stops at street level require less special construction, and passengers do not need to use stairs or ramps. However, buses mix with traffic on the ramps and frontage roads and generally must cross an intersecting street at-grade. Where traffic on surface streets is light, these disadvantages are lessened. However, where roads and streets operate at or near capacity, and where ramp terminals may be signalized, buses will experience delay.

Turnouts for Bus Stops

The basic design objective for a freeway bus turnout is to have the deceleration, standing, and acceleration of buses take place on pavement areas clear of, and separated from, the travel lane. Speed change lanes should be long enough to enable the bus to leave and enter the travel lane at roughly the average running speed of the highway without undue discomfort to passengers. The length of acceleration lanes from bus turnouts should be above the normal minimum values when buses leave and enter the main freeway lanes. This is because buses starting from a standing position have a lower acceleration capability than passenger vehicles. Normal-length deceleration lanes are suitable.

Figure 4-13 illustrates typical cross sections of bus turnouts for a normal section, a section through an underpass, and an elevated structure. The width of the bus standing area and speed-change lanes,

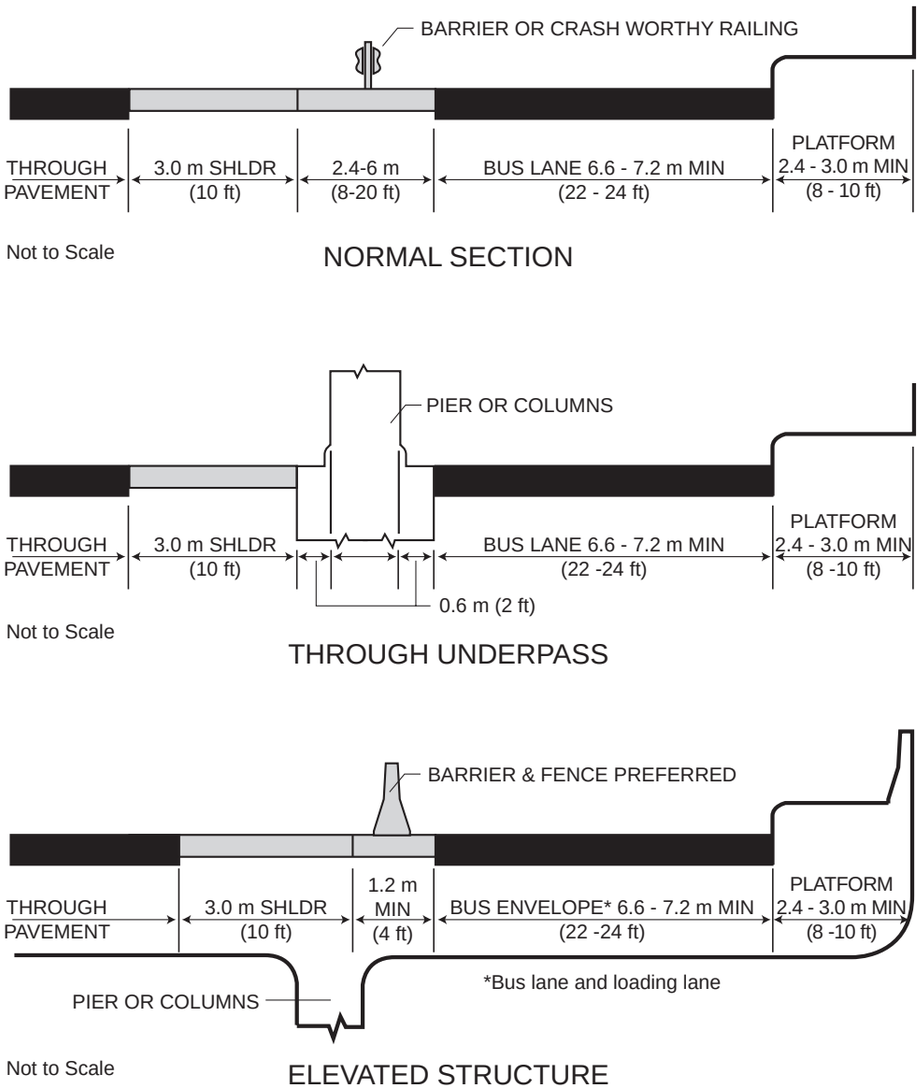


Figure 4-13. Bus Turnouts (*2*)

including the shoulders, should be 6.7 m (22 ft) to allow passing a stopped bus. Use applicable traffic control devices to discourage through traffic from encroaching on or entering the bus stop or station. Consider using pavement that contrasts in color and texture with the traveled lane to supplement/enhance these devices.

The dividing area between the outer edge of freeway shoulder and the edge of a bus turnout lane should be as wide as practical, preferably 6.0 m (20 ft) or more. In constrained cases, this width could be reduced to a minimum of 1.2 m (4 ft). A barrier usually is needed in the dividing area, and fencing is desirable to keep pedestrians from entering the main freeway lanes. Loading platforms should not be less than 3.0 m (10.0 ft) wide, and preferably 3.4 m (11.2 ft) wide to accommodate ADA requirements 4.5 m (15.0 ft). Weather protection is desirable especially in cold climates.

A median barrier should separate opposing travel directions along barrier-separated HOV lanes and bus-only roads. For busways, normal curbing with a fence can be used.

Errant crossings by pedestrians at stations should be discouraged. Median barriers generally should be continuous to prevent spearing (i.e., a head-on collision between a vehicle and an unprotected end of a guardrail or concrete barrier). Appropriate signing should discourage entry of passenger vehicles into the bus lanes at stations.

A bypass lane should be provided to allow vehicles to travel through a station without stopping, or to allow some buses skip stations. If a bypass lane is not provided, vehicles would have to stop and wait while buses drop-off and pick-up passengers, disrupting reliability. A 3.6-m (12-ft) through lane normally is considered.

Passing lanes around buses are essential along HOV roadways, as well as busways. However, when sufficient width is not possible for a through lane in each direction (especially along busways), a wide median buffer lane can be provided that opposing directions share.

Acceleration and Deceleration Lanes

Space should be provided to allow buses to decelerate to enter an on-line stop or station area and to accelerate and re-enter the main travel lane. The distance of the approach and departure area will depend on the mainline travel speeds, the length of the station, or platform area, and the vehicle mix authorized to use the facility.

Separate busways normally have restricted operating speeds for through buses in station areas 30 to 50 km/h (20 to 30 mph). Although full acceleration lanes of between 120 and 220 m (400 and 725 ft) are provided on some facilities, operating experience in Ottawa, Pittsburgh, and elsewhere has demonstrated that low bus volumes, professional drivers, and a controlled environment allow smooth and safe operation with acceleration and deceleration lanes as short as 21 m (70 ft). This suggests that distances of 30 to 45 m (100 to 150 ft) normally will be sufficient.

Longer deceleration and acceleration lanes are necessary where vehicles on freeway HOV facilities maintain higher operating speeds through station areas, such as on the San Bernardino Busway (I-10) and the I-110 Transitway in Los Angeles. Approach and departure lanes for buses on these facilities range from 636 to 848 m (2,100 to 2,800 ft), based on California design criteria and posted speeds of 75 km/h (45 mph), however, such distances are not practical where stations are closely spaced. More realistic lengths of 200 to 250 m (650 to 820 ft) should be considered where stations are relatively close.

Loading Area Options

The design of the loading lane and platform will depend on the operating characteristics of the facility. Both parallel and sawtooth designs may be used for platforms and loading areas. Parallel platforms frequently are found with existing on-line stations, whereas sawtooth designs are found with park-and-ride and off-line transit stations. Parallel platforms require less width but more length than shallow sawtooth platforms.

The parallel design allows buses to simply pull to the curb at a designated spot. The bus then pulls away from the curb and merges back into the through lane after picking up and dropping off passengers. This is preferable from a transit operations standpoint since it does not require bus operators to maneuver in and out of bus bays. It is also more efficient for operators that deploy a variety of buses in their operating fleet. The loading lane is located adjacent to the platform area. With parallel platforms, the loading lane is typically 3.6 m (12 ft).

The sawtooth design provides staggered berths for buses to pull in and pull out. Wider loading lanes are needed with shallow sawtooth platforms to accommodate the necessary bus maneuvers. Typical widths for sawtooth platforms are in the range of 4.8 to 6.1 m (16 to 20 ft). Appendix D includes a more information for bus passenger interface facilities, including guidance on loading area cross sections and design considerations.

Passenger Platform Components

Platform Length

The length of the passenger platform area will depend on the number of transit vehicles anticipated to use the facility, projected passenger demand, and the types of buses. The general length of platforms at existing on-line stations are 30 m (100 ft) in Pittsburgh, 55 m (180 ft) in Ottawa, and 61 m (200 ft) or more on the San Bernardino Busway. At least 12 m (40 ft) is needed at a parallel loading area for a standard bus and 18 m (60 ft) is needed for an articulated bus. These dimensions do not include maneuvering space. Stations normally should permit two vehicles to receive and discharge passengers at the same time. This suggests minimum lengths of 36 m (120 ft) for articulated buses and 24 m (80 ft) for standard buses. Major stations where buses or dwell times are long may need additional space (see Chapter 3 for further details). These dimensions do not include maneuvering space and do not account for buses with front-end bike racks.

Platform Width

The width of a platform will depend on the number of passengers projected to use the facility, especially during the peak hour, and on the space requirements of other amenities that may be provided. Width also will be affected by the available right-of-way, which in a constrained freeway median environment typically will be minimal. Passenger platform widths of 3.0 m (10 ft) are used in Pittsburgh, and 3.6 m (12 ft) in Ottawa. Additional space will be needed for passenger waiting areas, pedestrian or feeder bus access, and other amenities. At least 3.0 m (10 ft) is needed to meet ADA requirements comfortably; about 4.5 m (15 ft) is desirable where possible. These dimensions do not include a shelter.

Waiting Areas, Access, and Amenities

Stops serving as stations frequently include additional features and amenities. Stairways, elevators, pedestrian ramps, benches, shelters, enclosed and possibly climate-controlled waiting areas, solar powered

lighting, newspaper racks, bicycle parking, vending machines, and other amenities should be considered in the design process. Passenger shelters or enclosed waiting areas should be provided within the freeway environment. The ADA regulations require that the stations be fully accessible to all individuals. These designs should follow appropriate federal, state, and local guidelines. The design of the waiting areas must also consider variability in location of lifts for each type of coach that will serve the platform.

Passenger safety and security should be carefully considered in the development of station plans. The principles of CPTED (Crime Prevention Through Environmental Design) should be followed. The premise of CPTED is that the physical environment can be changed or managed to produce behavioral effects that will reduce the fear and incidence of crime, thereby improving quality of life and enhancing profitability for businesses. Station and access lighting, visibility, transparency, emergency communications systems, and remote monitoring are among the elements of a safe and comfortable transit environment. Solar lighting is desirable to reduce maintenance costs, as it works without connection to an electric utility.

Design features that can enhance security include characteristics of the station furniture. Benches can be designed to include window screens. These can provide a noise barrier behind the patron, while still providing visibility for law enforcement through the stations. Screens also protect riders from debris coming from the mainline lanes of the freeway, whether accidental or intentional.

Pedestrian Access and Environment

Pedestrian Bridges

Grade-separated pedestrian facilities allow pedestrians and motor vehicles to safely cross at different levels, either over or under a roadway. They provide pedestrians with a safe refuge for crossing the roadway without vehicle interference. Pedestrian grade separations should be provided where pedestrian volume, traffic volume, intersection capacity, and other conditions favor their use, although their specific location and design require individual study. They may be warranted where there are heavy peak pedestrian movements, such as at CBDs, shopping centers, schools, or special event centers, in combination with moderate to heavy vehicular traffic or where unusual risk or inconvenience to pedestrians would otherwise result. Pedestrian separations, usually overpasses, may be needed at freeways where intersecting cross streets are terminated. On many freeways, highway overpasses for cross streets are limited to three-to-five block intervals. This situation imposes an inconvenience on pedestrians desiring to cross the freeway, and may require pedestrian grade separations. For some transit users with limited mobility or stamina, it may actually restrict the use of transit. Local, state, and federal laws and codes should be consulted for possible additional criteria concerning need, as well as additional design guidance.

Where frontage roads are adjacent to the freeway, the pedestrian crossing may span the entire frontage road or the separation of the through roadway. Separations of both through roadways and frontage roads may not be justified where frontage roads carry light and relatively slow-moving traffic. In some cases, the separation should span the frontage roads as well. Fences may be needed to prevent pedestrians from crossing the arterial at locations where a separation is not provided. Pedestrian crossings or overcrossing structures at arterial streets are not likely to be used unless they are attractively designed and easy to use.

Generally, pedestrians are more reluctant to walk under versus over a freeway. That reluctance may be minimized by locating the undercrossing on line with the approach sidewalk and ramping the sidewalk

gently to permit continuous vision through the undercrossing from the sidewalk. Good sight lines and attractive lighting are needed to enhance a sense of security. Long undercrossings may require ventilation.

Pedestrian-accessible ramps should be provided at all pedestrian separation structures. Where warranted and practical, both a ramp and a stairway should be provided. Elevators should be considered where the length of ramp would result in a difficult path of travel for persons with or without a disability.

Walkways for pedestrian separations should have a minimum inside clear width of 2.4 m (8 ft). Greater widths may be needed where pedestrian traffic is exceptionally high, such as in the downtown areas of large cities and around sports venues, where the structure is screened creating a tunnel effect, or where bicycles will likely use the facility. Refer to the AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* and the *AASHTO Guide for the Design of Bicycle Facilities* for additional information.

A serious potential problem associated with pedestrian overcrossings and highway overpasses with sidewalks is vandals dropping objects into the path of traffic moving under the structure. The consequences of objects being thrown from bridges can be serious. There are frequent reports of fatalities and major injuries caused by this type of vandalism. There is no practical device or method that can be universally applied to prevent a determined individual from dropping an object from an overpass. Since small objects can be dropped through mesh screens, a more effective deterrent is a solid translucent enclosure.

Plastic overcrossing enclosures are expensive and may be insufferably hot in the summer. They obscure and darken the pedestrian path, which could be conducive to other forms of criminal activity. Any completely enclosed pedestrian overpass has an added problem that someone may walk or play on top of the enclosure. Continuous kick plates can be considered along the length of the bridge to prevent objects from being accidentally kicked onto the roadway.

In areas subject to snow and icing conditions, the possibility that melting snow and ice may drop from the roof of a covered overpass and fall onto the roadway below should be considered. Roofs can be designed in a barrel shape to prevent accumulation of snow.

- The general need for economy in design and the desire to preserve the clear lines of a structure unencumbered by screens should be carefully balanced against the need to provide safe operations for both motorists and pedestrians. Screens should be considered when an overpass is constructed at the following locations:

- On an overpass near a school, a playground, or elsewhere if the overpass is expected to be used frequently by children unaccompanied by adults;

- On all overpasses in large urban areas used exclusively by pedestrians and not easily kept under surveillance by police; or

- On an overpass where the history of incidents on nearby structures indicate potential for objects being dropped from the overpass and where it seems evident that increased surveillance, warning signs, or apprehension of a few vandals will not effectively alleviate the problem.

More complete information on the use of protective screens on pedestrian overpasses is available in the AASHTO *Roadside Design Guide.*

Figure 4-14. Typical Pedestrian Overpasses on Major Highways (*2*)

Pedestrian Circulation: Supporting Traffic Control

Appropriate signing, markings, and other traffic control design devices (e.g., flashing beacons, pedestrian push-button countdown signals, and radar-type speed signals) should be used to warn and control vehicular traffic on service roads and cross streets entering a stop or station area. It may also be desirable to include stop signs at the entrance to the station area. Crosswalks should be made as visible as possible with signs and additional markings, if necessary.

Table 4-4. OSHA Permissible Noise Exposures (*11*)

Duration per Day, hours	Sound Level, dBA
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
14 or less	115

Pedestrian Comfort

As a general goal, the noise level in station areas should not exceed 75 dBA, consistent with EPA guidelines. This goal is more stringent than maximum noise levels established by the Occupational Health and Safety Administration (OSHA). (*9*) Using OSHA's permissible exposures, noise levels in the station at any time should not exceed 105 dBA (see OSHA standards for one hour of exposure in Table 4-4). Appropriate sound barrier elements should be included in the station design to meet this maximum noise exposure requirement.

In addition to noise, pedestrians should be protected from physical hazards. Screens or canopies should be located to protect patrons from roadway dust, fumes, or splash, and should be capable of withstanding flying objects from the roadway. Screens should act as a noise buffer and provide adequate visibility for law enforcement.

Station Height Above Freeway Mainline

Raising the station level above the main lanes can provide the following benefits:

- Safety from errant vehicles
- Pedestrian comfort (reduced noise and general separation from freeway main lanes)

The platform should not reduce visibility from main lanes, which could result in decreased security. Visibility can make pedestrians feel more comfortable and reduce the need for other forms of security, such as closed-circuit television. Also, the height of the station can affect the length of ramps leading to and from the station. Depending on the infrastructure upstream or downstream of the station, ramp lengths can have a significant effect on construction costs, as more of the freeway mainline would be affected. However, desired vertical clearances must be maintained.

ADA and Accessibility

Stairs, Ramps, and Escalators

Bus stops at the freeway level need stairs, ramps, escalators, possibly elevators, or combinations of these for passenger access between the freeway station and local street levels. Because transit facilities must be accessible to persons with disabilities, stair-only access at transit stops is not permitted for new construction/reconstruction.

Stairways, ramps, and elevators at transit stops should be easy to use and present an inviting appearance. This effect is partially accomplished by providing railings and ample lighting both day and night and by providing landings at every 0.8 m (2.5 ft) change in elevation. A covering over the stairways, ramps, and platforms also may be desirable. Stairways should be located where the climb will be minimal, preferably not more than 5.4 to 6.0 m (18 to 20 ft).

Stairs and ramps typically are installed at bus stops in built-up urban developments. They are also well adapted to bus stops in suburban or park-like areas. Railings are desirable and usually necessary; combinations of ramps and stairs may be appropriate at some locations. If bus routes serve a large percentage of older passengers, are extremely busy, or require a very long ramp climb, the use of escalators should be considered. Provisions for persons with disabilities are necessary, and are more desirable than a series of switchback ramps. Wide passageways and doors and the elimination of other barriers is desired. The Americans with Disabilities Act Accessibility Guidelines (ADAAG) provides further guidance on the design of facilities for persons with disabilities.

Bicycle Storage and Access

Bicycle access to station platforms should be provided where the bus service has or later may have bike-on-bus (bicycle rack) capability. Examples of bicycle accommodations are provided in the AASHTO *Bicycle Design Guide*. (*3*)

On-Line Stations

Transit stations traditionally have been implemented in two settings along a freeway or highway—either off-line or on-line. Off-line stations are located outside the freeway right-of-way, sometimes connected to the freeway either by a direct ramp or to a median HOV lane by a median direct access ramp. On-line stations are located either within the freeway median or on the outside (right side) shoulders, and are preferable for bus rapid transit and other through bus services.

Stations along median bus (or HOV) lanes enable passengers to transfer with a minimum of en route time penalty. The station collection and distribution function should mirror other forms of fixed transit guideways and embody the service principles described for an exclusive bus rapid transit operation.

Table 4-5 provides recommended geometries for selected characteristics of highway transit stations, including passenger platform, bus lanes, and necessary buffers. These characteristics are identified for both

I-110 Transitway, Los Angeles

I-10 El Monte Busway, Los Angeles

Figure 4-15. Example High-Speed Freeway On-Line Stations

Table 4-5. Recommended Cross Section Dimensions

Component	Side Platform Stations			Center Platform Stations	
	Desirable	Reduced	Minimum	Desirable	Reduced
Platform	4.2–4.5 m (14–15 ft.)	3 m (10 ft)	2.4 m (8 ft)	4.5 m (15 ft)	3.6 m (12 ft)
Bus Loading Lane	3.6 m (12 ft)	3.3 m (11 ft)	3.0 m (10 ft)	3.6 m (12 ft)	3.6 m (12 ft)
Through Lane	3.6 m (12 ft)	3.6 m (12 ft)	n/a	3.6 m (12 ft)	3.6 m (12 ft)
Through Lane Buffer	1.2 m (4 ft)	0.6 m (2 ft)	n/a	1.8 m (6 ft)*	0.6 m (2 ft)
Center Buffer or Barrier	3.0 m (10 ft)*	0.6 m (2 ft) 1.8 m (6 ft)	0.6 m (2 ft)	n/a	n/a
Total Envelope	28.5 m (93 ft)	23.2 m (74 ft)	15.2 m (50 ft)	27.6 m (90 ft)	19.7 m (64 ft)

* Could be as little as 1.2 m (4 ft) for busways.

side and central platform stations. A key factor in determining the extent of station geometries is the need for and availability of right-of-way for through lanes as well as their associated buffers. Note that additional width may be required to accommodate vertical circulation elements (stairs, elevators, or escalators), particularly where the elements are at the center of the platform, rather than at either end.

Choosing a Station Type

A variety of factors contribute to the type and location of a station, and to the arrangement of lanes and the platform within the station. For example, the decision to locate a station in the median or on the right side of the main freeway lanes will depend on the location of bus/HOV lanes (left or right side), the surrounding land uses adjacent to the facility, and the available right-of-way in the median for a station. Ideally, an on-line station should enable buses to pass other buses stopped or stalled at the platform. Therefore, a second through lane, located adjacent to the bus loading lane, is desirable since it provides operating flexibility for express non-stop bus service. However, where there is not enough space to include through lanes in each direction, a wide buffer between the two bus loading lanes can act as a safety buffer and also double as a passing lane in emergency situations. This buffer could include a raised mountable curb. Where anticipated bus volumes are low, a passing lane may not be needed, because of the low likelihood of two buses being at the station at the same time. Finally, wherever median stations are employed on dedicated lanes and busways, buses can provide doors on both sides.

The buffer strips that separate the station lane from adjacent lanes should be provided when the adjacent lane serves buses (and HOVs) that are passing the station area without stopping. Where the adjacent lane only serves as an emergency breakdown lane, it may not be necessary.

Figure 4-16 shows a decision tree to assist in choosing station design types. Table 4-6 compares the features, and Table 4-7 compares the advantages and disadvantages of each option. Key considerations include:

- The overall envelopes for side and center platforms are about the same.
- The side platforms provide simple, conventional bus operations.

- The center platform requires crossovers of bus movements. This could result in delays when bus volumes are heavy. Center platforms can avoid crossovers if there are doors on both sides of the buses.
- Bus stations on ramps may have cost advantages but require buses making stops to both leave and enter the freeway, HOV, or busway lanes.

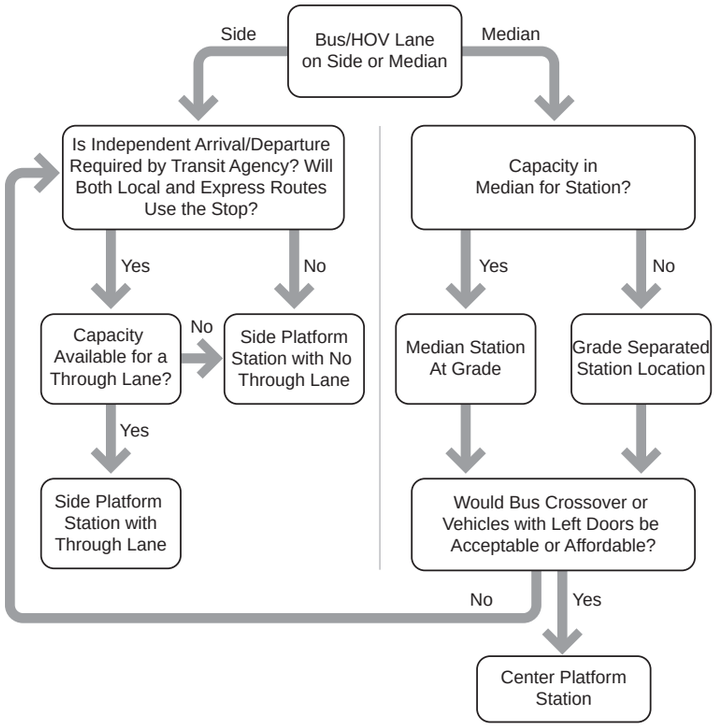


Figure 4-16. Choosing a Station Type (*2*)

Table 4-6. Attributes of Platform Locations

Attribute	Side Platforms	Median Platforms	Platform on Ramps Elevated
Through Lane	Around rear of platform	Barrier separated from loading lane	Around and below ramp
Platform	Two 3.0–3.6 m (10–12 ft)	One 3.6 m (12 ft)	Cantilevered over through lanes
Access	Separate loading lanes next to median barrier	Loading lanes that reverse on each end of platform	Via typical two-way HOV ramp from median
Traffic Control	None	Stop signs and possibly automated gates to preclude wrong way movements	Signed or signalized at intersection on top of ramp
Overall Width* (assuming concurrent flow lanes with barriers)	23–28 m (76–92 ft)	23–28 m (76–92 ft)	Controlled by ramp. No extra width for platforms. Approx. 24.6 m (80 ft)

* Desirable and reduced dimensions.

Table 4-7. Advantages and Disadvantages of Platform Locations

	Side Platforms	Median Platforms	Platform on Ramps Elevated
Advantages	Considered safer than center platform	Less overall width	Serves bus and carpool needs
	Requires no traffic control	More protected platform area	Reduces added width for platforms
	Closest to accepted practice	Allows common vertical pedestrian facilities	Potential for lower cost
Disadvantages	Wider and more costly	Harder to enforce	Less amenable to protected pedestrian access
		Requires traffic control for reverse movements	Requires new local access from freeway
	Harder to get from one platform to the other	Needs doors on both sides of buses	Not usually desirable for BRT operation
		Creates bus-bus conflicts	

Right-Side Stops

Figures 4-17 and 4-18 show bus stops on the right side of freeways in Los Angeles and Seattle. Bus stops logically are located at or near major intersections where passengers can use the grade-separation structure for access from either side of the freeway.

Figure 4-19 shows design concepts for example freeway bus stops. Figure 4-19(A) shows an arrangement of stops at an overcrossing street, without an interchange. The turnouts and loading platforms are placed under the structure, requiring greater span lengths or additional openings. Each stairway/ramp system should be located on the side of the cross street used by most passengers. Two additional stairways can eliminate any crossings of surface streets by transferring riders who do not need to use the elevators.

Figure 4-17. Example of Right-Side, On-Line Station Stop, I-110, Los Angeles, California

Figure 4-18. Example of Right-Side, On-Line Stop, I-5, Seattle, Washington

Figure 4-19 also shows an arrangement at an undercrossing street without an interchange. As indicated at the top left of this exhibit, platform exits and entrances may be connected directly to adjoining developments such as public buildings and department stores.

Sometimes transit stops are needed at locations other than at overcrossing streets, such as in outlying areas or in built-up districts where it is neither feasible nor desirable to provide stops at cross-street structures. Such stops preferably should be located opposite the cross streets intercepted by frontage roads or major passenger walkways. A grade separated pedestrian access should be provided to make bus stops usable from either side of the freeway.

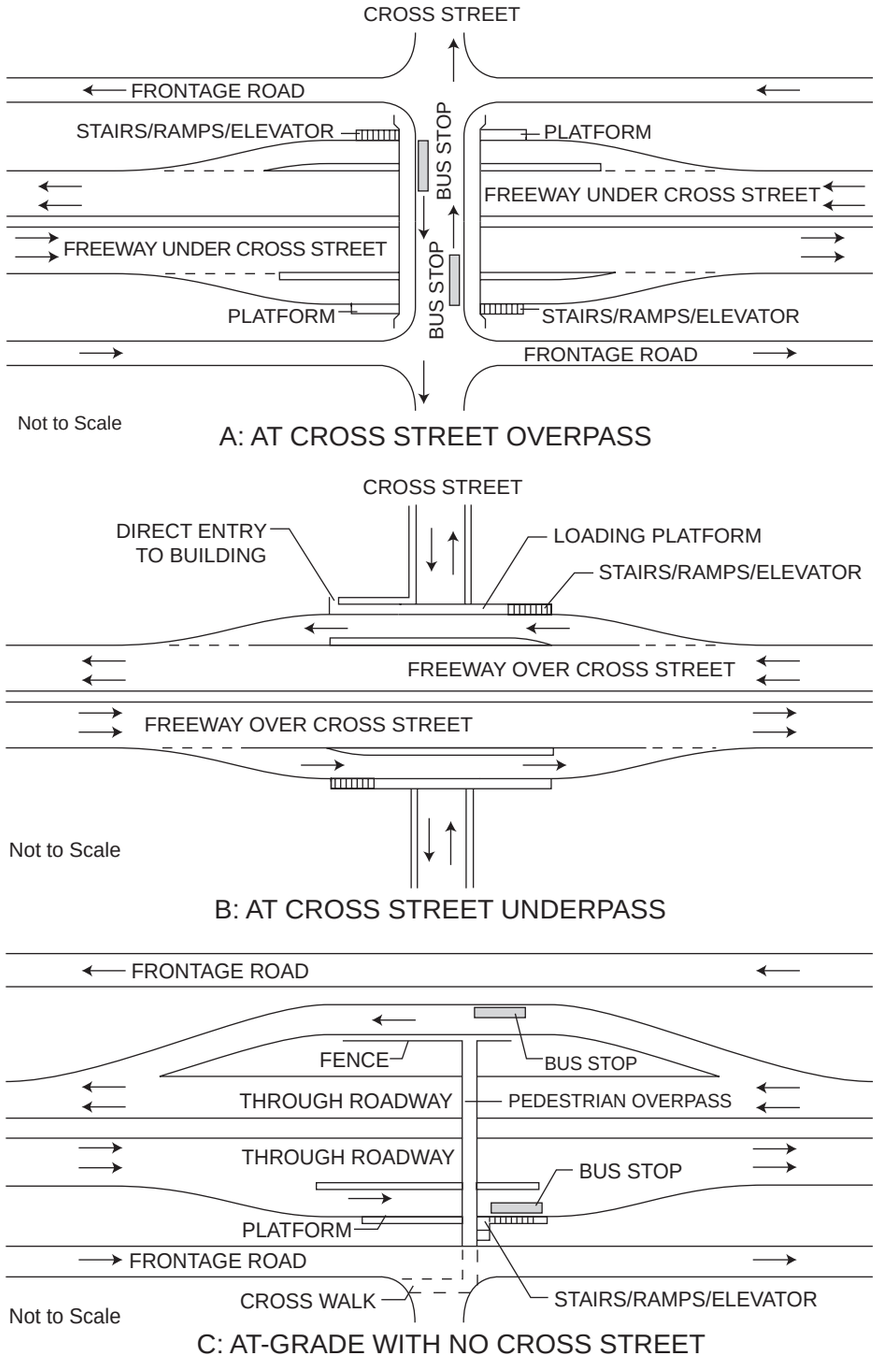
Figure 4-19 (C) illustrates two likely layout plans. In the lower half of the exhibit, the turnout is located at the freeway level under the pedestrian structure. Pedestrians may reach the structure by stairs or ramps. An alternative layout, shown in the upper half of the figure, features a turnout located at the level of the frontage road, eliminating the need for passengers to climb stairs or ramps.

Figure 4-20 shows illustrative design concepts for bus stops at the freeway level and at an interchange. In Figure 4-20 (A), the entrance to the turnout is located beyond the exit ramp nose, and the exit from the turnout is located in advance of the entrance ramp nose. In Figure 4-20 (B), buses use the freeway ramp exit to enter the turnout. In this case, the bus stop is usually located through a separate structure opening. Such consolidation of access points improves the efficiency of through and ramp traffic. Bus drivers readily adapt themselves to the appropriate route to enter and exit the bus turnout.

Figure 4-21 is an example layout for right-side stops in a cross section and plan. The buffer area should be provided for the condition where there is a bus-only lane on the approach to the station. In this case, the lane adjacent to the stop serves as a through lane. When buses exit and return to the freeway lane, the lane adjacent to the stopping lane serves as a breakdown lane and the buffer area is not necessary.

Median-Side Stops

The location where a bus uses a stop in a freeway median is most likely to coincide with bus use of a median bus/HOV lane or roadway. These lanes usually serve a mix of buses, carpools, vanpools, and



NOTE: Elevators/stairs will need to be outside the clear zone for vehicular traffic on the roadway or be shielded by a barrier.

Figure 4-19. Right-Side Bus Stops at Freeway Level (*2*)

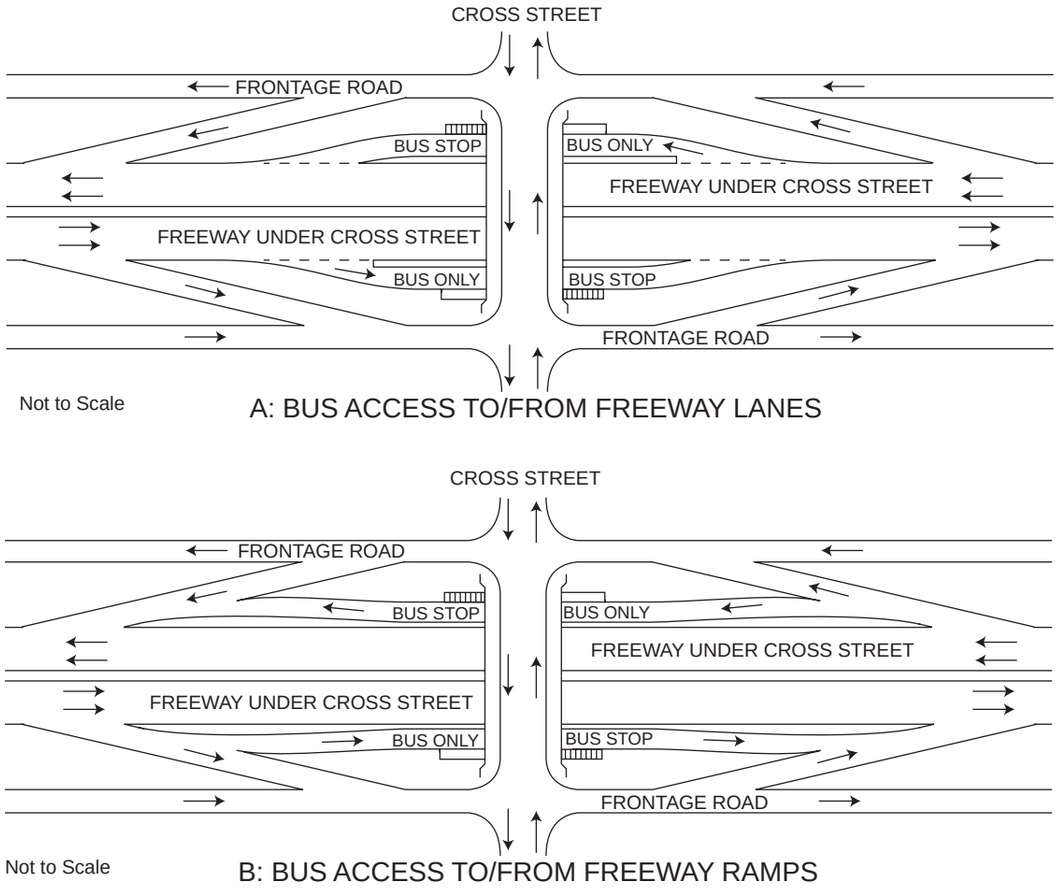
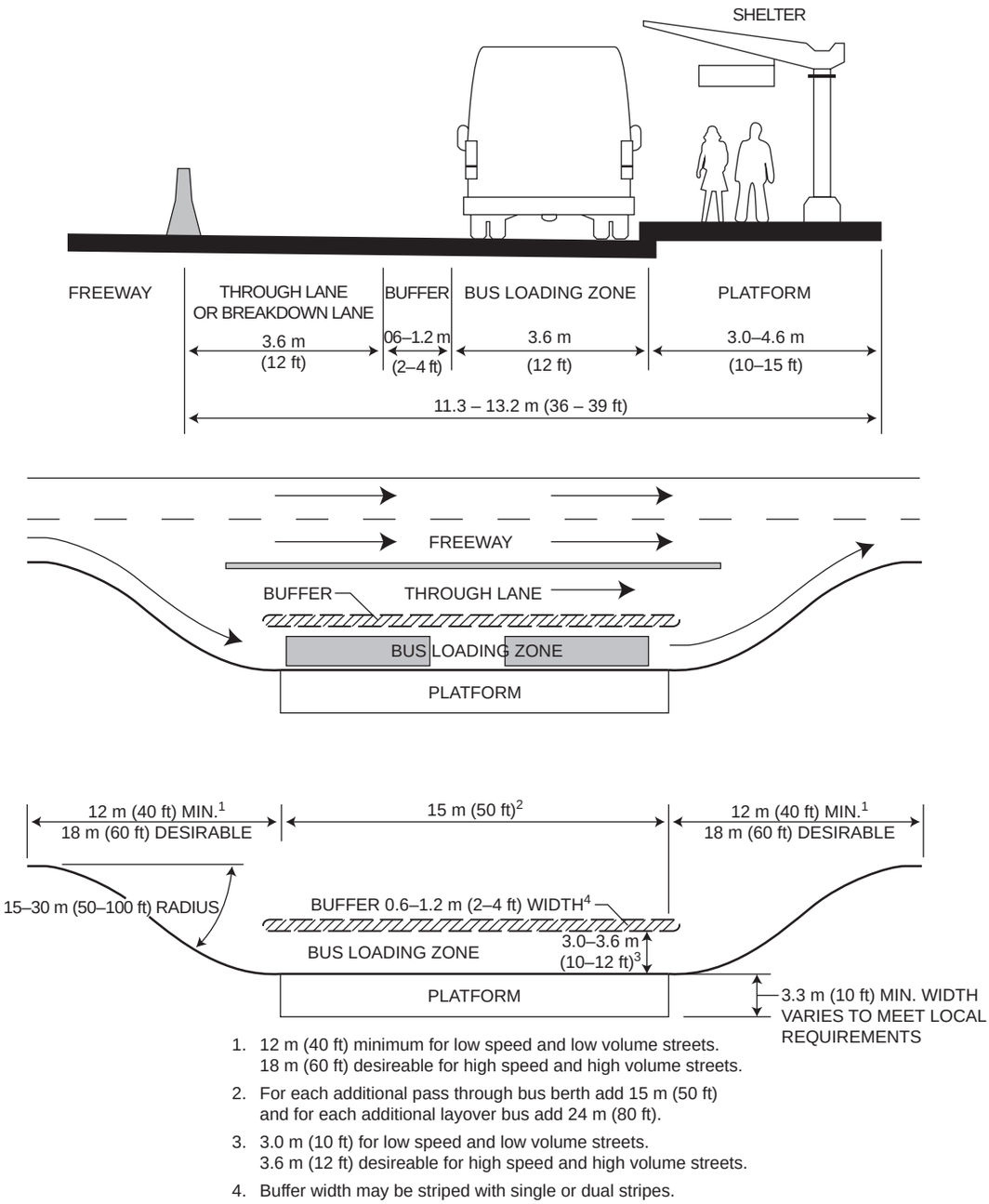


Figure 4-20. Right-Side Bus Stops at Freeway Level—Diamond Interchange (*2*)

motorcycles and are designed for high speeds and high volumes approaching 1,500 vehicles/lane. Median on-line stations offer the advantage of truly rapid bus transit with minimum delay time for transferring passengers. However, under these operating conditions, designing a station alongside high-speed travel lanes poses safety and operational challenges. Segregating stations from general purpose and HOV traffic and creating grade-separated pedestrian access can be costly.

Various design documents published since the 1970s have offered guidance for freeway on-line stations, but few implemented examples can be found in the United States other than those usually associated with rail transit lanes as in Chicago, Portland, Philadelphia, Toronto, and Washington. As of 2005, the I-110 freeway in Los Angeles was the only corridor in the United States showing examples of median on-line bus stations in operation. Several other high-speed, on-line station designs have been implemented along the I-10 El Monte Busway in Los Angeles, but they are not located in the freeway median. Plans for on-line bus stations along freeways are being considered in several metropolitan areas.

When transit facilities are within a freeway median, access to the transit usually is provided from cross-road interchange locations. Median station facilities may not be attractive or comfortable for passengers



1. 12 m (40 ft) minimum for low speed and low volume streets. 18 m (60 ft) desireable for high speed and high volume streets.
2. For each additional pass through bus berth add 15 m (50 ft) and for each additional layover bus add 24 m (80 ft).
3. 3.0 m (10 ft) for low speed and low volume streets. 3.6 m (12 ft) desireable for high speed and high volume streets.
4. Buffer width may be striped with single or dual stripes.

Figure 4-21. Sample of Right-Side Stops

because of noise and proximity to high-speed traffic. Passenger safety is difficult to provide. Placing passenger facilities over the mainline may create security issues and be expensive. For these reasons, access ramps to off-line transit stations sited a short distance from the freeway, or placement of transit station facilities on the side of the freeway, typically are preferred based on current design and operational practice.

Median stations are not well suited for bus rapid transit. Through lanes must be separated by barriers from bus loading lanes to prevent passengers from crossing roadways. Platforms and pedestrian access require the same considerations as for side platform designs. High-speed settings require considerable acceleration and deceleration distances, along with tapers to transition freeway lanes around the station. Stations at grade in freeway medians can create an increased potential for disruption of transit operations, since freeways may be subject to closures for major repair or reconstruction. Noise and visual issues also adversely affect transit patrons.

Side Platforms

The most typical application of an on-line station applies side platforms similar to the busway on-line stations. Dimensions for each platform length and width are governed by the same variables (see Appendix D), but the high-speed freeway setting requires protecting the rear of each platform by a barrier or wall. Opposing flow bus or HOV movements through the station require full barrier separation to prevent wrong-way movements. Attenuation and barrier protection should protect the front of the platform and provide shelter from errant motorists. A transition barrier should be applied some distance from the platform to serve this purpose.

Pedestrian access needs full-grade separation treatments above or below the freeway to the station platform and convenient vertical transportation. Adequate lighting, shelter, and security are important.

Only buses are permitted to access the station bus-loading lane because of the limited maneuvering room available for loading vehicles. Loading lanes are typically 3.6 to 4.2 m (12 to 14 ft) wide. Through lanes are 3.6 m (12 ft) wide and include a protective shoulder area next to the rear of the platform of 3.0 m (10 ft).

Median transit stations can be provided by widening the envelope on each side of median lanes or barrier-separated bus/HOV roadways to provide bus loading lanes and passenger platforms on each side of the through lanes. When there are wide separations between opposing freeway lanes, the stations can be situated to the left of the through bus/HOV lanes.

Figures 4-22 and 4-23 depict examples of median stations with and without breakdown/bypass lanes, respectively. Both plans and cross sections are shown. Figures 4-25 through 4-28 provide examples of median bus lane stations in Los Angeles and Seattle.

Project Example: I-110 (Harbor Freeway), Los Angeles, California

Buses on I-110 follow bus-only lanes that diverge left from median HOV lanes to allow stops at on-line stations. Some stations offer elevated passenger walkway access to platforms from nearby local streets and centers. There are HOV passing lanes to the outside of the stations, but no bus bypass lane in the bus platform area. Figure 4-24 shows a typical on-line transit station on I-110 in Los Angeles. Figure 4-25 shows the station with vertical pedestrian access to the arterial below.

Project Example: Mountlake Terrace Station, Seattle, Washington

Puget Sound's regional transit service, Sound Transit, is implementing an on-line freeway transit station to serve a park-and-ride facility in Mountlake Terrace, Washington. Figure 4-26 and Figure 4-27 present artist renderings of the proposed station. The station will be located in the median of I-5. Buses will exit left from the HOV lanes to new transit-only ramps to access the facility. A pedestrian bridge will span the northbound freeway lanes, connecting the park-and-ride facility to the future transit station. The

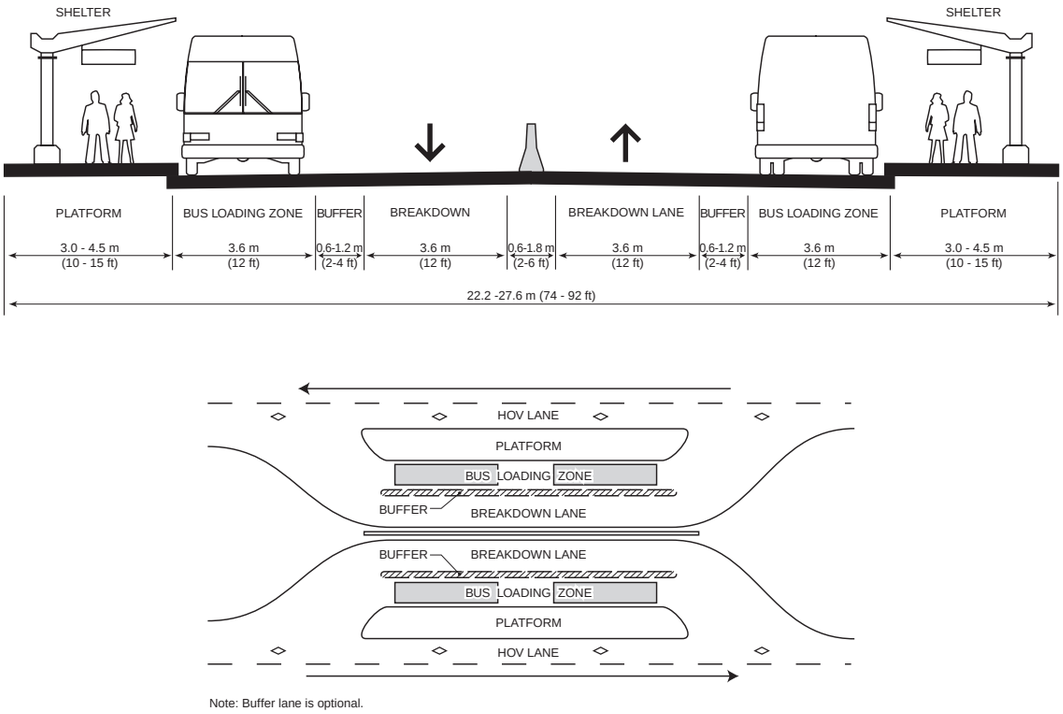


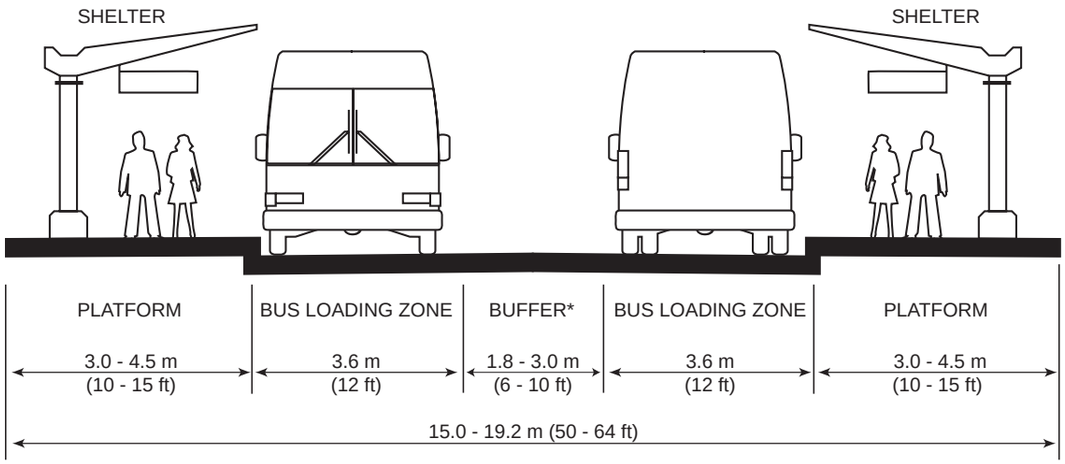
Figure 4-22. Sample Median-Side Stop, Side Platform with Through Lane

preferred alternative for Sound Transit's new Mountlake Terrace in-line station includes a range of options for the layout and geometry. The northbound and southbound platforms will be separated by 10.2 to 10.8 m (34 to 36 ft.) to allow for a 3.0-to-3.6-m (10-to-12-ft) buffer between the northbound and southbound 3.6-m (12-ft) travel lanes. The platform length will be 48 m (160 ft) long to provide two 18-m (60-ft) berths with 12.2 m (40 ft) of maneuvering room between. The width of the platform will be either 3.0 or 3.6 m (10 or 12 ft). The transit-only on- and off-ramps will connect to left-side HOV lanes and have proposed widths of 7.2 m (24 ft): 0.6 m (4 ft) left shoulder, 3.6 m (12 ft) travel lane, 2.4 m (8 ft) right shoulder.

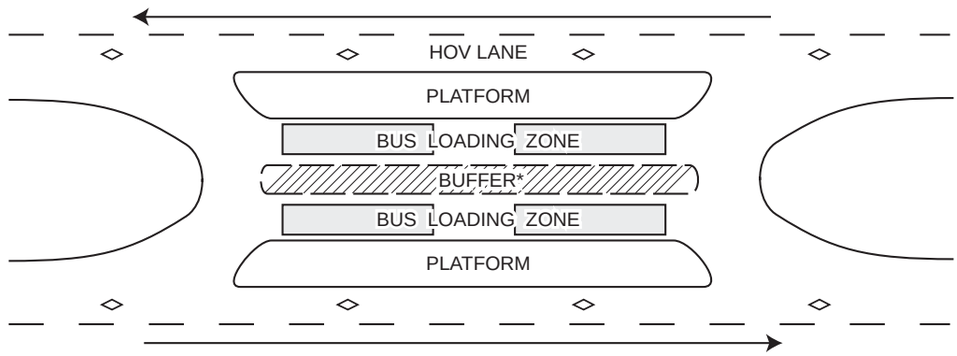
Center Platform

The center platform design for an on-line bus station in a freeway median attempts to reduce the overall width of the station area by condensing platform requirements and crossing over at the bus loading areas "English style," so that bus doors align properly to the parallel bays alongside the platform. This operation requires controls to protect the conflict points where bus paths cross. One state design guide suggests posting stop signs where the acceleration lane intersects the deceleration lane because of the lower speed that buses would be traveling. Buses could be required to stop in both directions. Another potential issue is controlling wrong-way movements by errant motorists where cars and vanpools use priority lanes. One solution proposes gating the exit ramps so that only buses can enter the deceleration lane. Only one center platform layout is in operation in the United States, on the I-110 transitway in Los Angeles. This example applies stop signs at conflict points but no gating.

The need for the crossover could be eliminated by either operating dedicated buses with left-side doors exclusively in the corridor (as on the TransMilenio arterial busway in Bogotá), or by using buses with



* A 10 foot buffer allows for bypassing loading buses.



NOT TO SCALE

Figure 4-23. Sample Median-Side Stop, Side Platform with No Through Lane

Photo courtesy of Caltrans.

Figure 4-24. On-Line Station on I-110, Los Angeles, California

Figure 4-25. Pedestrian Access on On-Line Station on I-110, Los Angeles, California

doors on both sides of the vehicle. This involves using the right-side door to pick passengers up on the street and using the left-side doors where a center platform is provided.

Figure 4-28 provides an example layout for median-side stops with a center platform in cross section and plan. The lanes adjacent to the bus loading lanes enable buses to pass around a stopped bus ahead. This condition is not likely unless bus volumes are high, which would also increase conflicts where bus flows cross each other.

Figure 4-26. Mountlake Terrace Station on I-5, Seattle, Washington

Image courtesy of Sound Transit.

Figure 4-27. Mountlake Terrace Station on I-5, Seattle, Washington

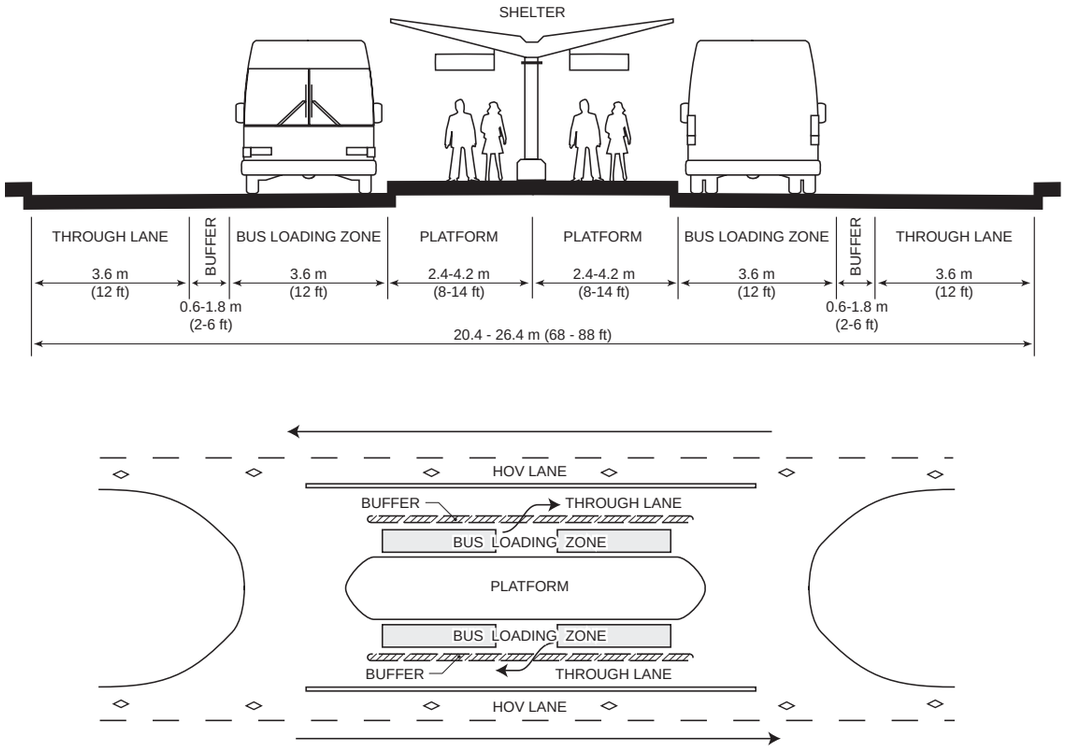


Figure 4-28. Sample Median-Side Stop, Center Platform

Station Functions on Direct Access Ramps

Similar on-line transit services can be handled by a direct access ramp that may also serve other bus routes and HOVs (see Figure 4-29). This approach places the side platforms on the ramp grade separation over (or under) the freeway. Buses use the ramp to load and unload passengers, then re-enter the bus/HOV lane on the other side. Priority vehicles may use the same ramp to enter and exit the HOV lane. The over or under crossing street becomes a new freeway access location for HOVs only. This design may augment a freeway grade separation where no general purpose ramps exist.

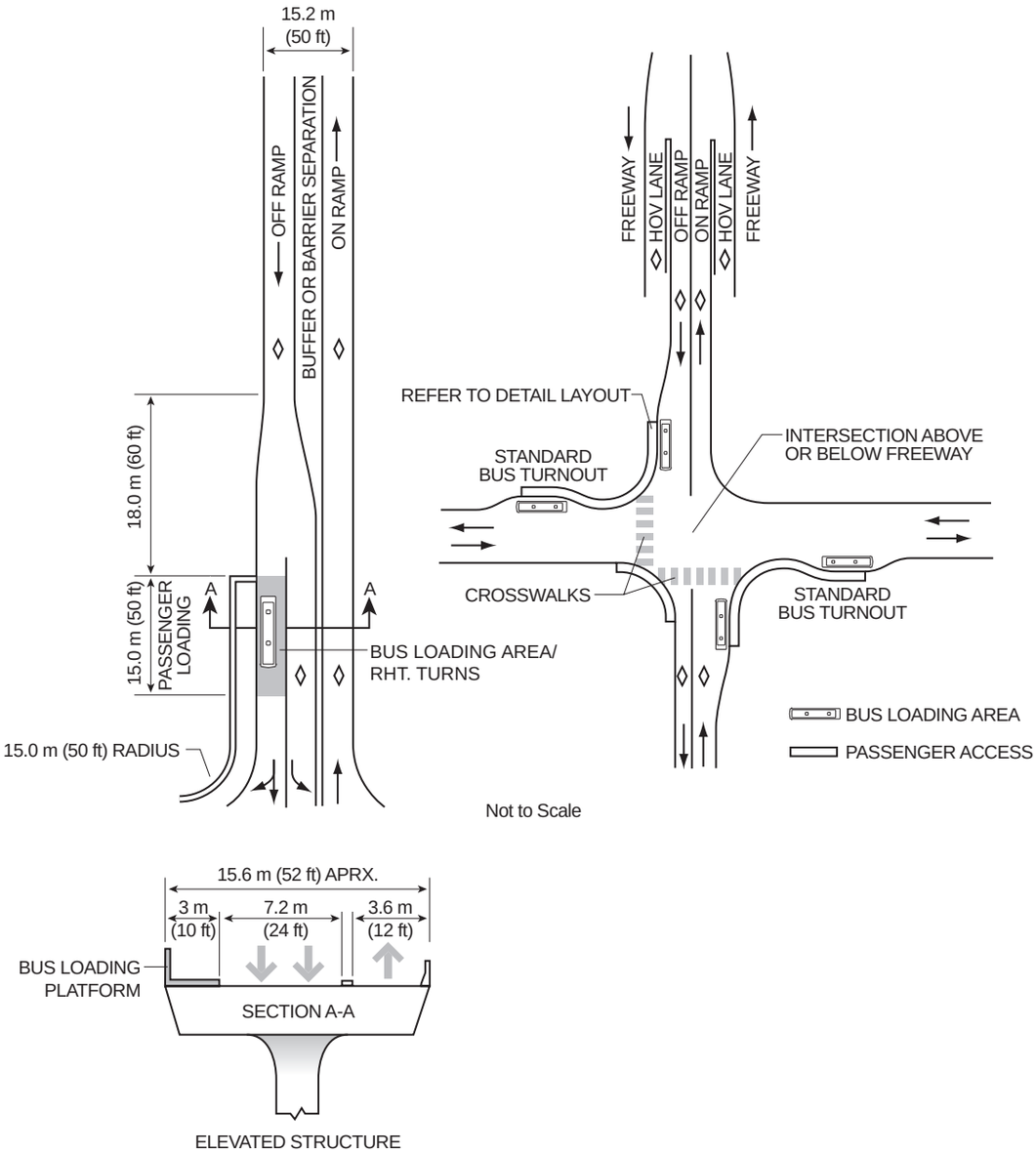


Figure 4-29. HOV Direct Access Ramp Serving Bus Transfers at an Intersection (*7*)

An alternate treatment would place the bus stops on the far side of the HOV ramps at the intersection. This would entail some modification of the ramp structure to allow HOVs to pass stopped buses. A far side stop is equally applicable.

Off-Line Stops/Stations at Arterials/Interchanges

Stops Involving Ramps

Bus transit stops may be needed near a local freeway interchange. In interchange design and operation, planners must recognize the need to transfer passengers.

The most common strategy is to operate buses on the outer (right) lanes or shoulders of the freeway, and to provide off-line bus stops either adjacent to the freeway interchange ramps and service roads or through access driveways with ramps. The key to successful operation is to allow the freeway buses to exit and re-enter the freeway as quickly, reliably, and comfortably as possible, while providing adequate stop facilities at the crossing street to facilitate passenger boarding and transfer in a safe and comfortable environment without disrupting vehicle traffic. The full diamond interchange is well suited to off-line transit interface.

The partial cloverleaf (parclo) layout supports off-line stops, but it must accommodate bus movement between exit and entry ramps. If one or both loop ramps exhibits low traffic volumes (i.e., fewer than 100 vehicles in the peak hour), planners could consider replacing the loop with a left turn at the off-ramp terminus signal. This design change would free up flexibility for transit facility options and provide property that could be used for a park-and-ride lot or transit station.

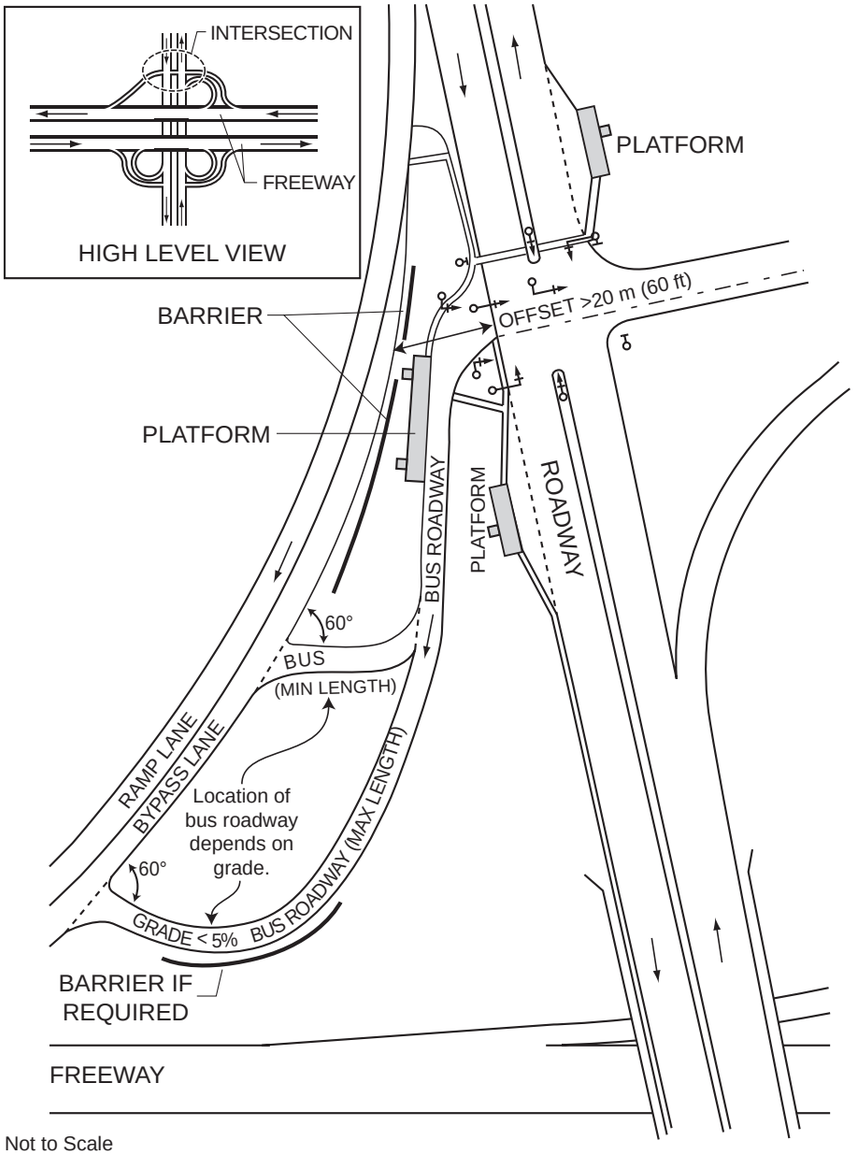
Figures 4-30 and 4-31 show various typical bus stop configurations. These are well suited to interchanges with ramp metering and accompanying bus/HOV bypass lanes. The ramp terminals at the arterial road should be signalized. Advanced or extended green times when buses arrive should be provided where feasible.

Stops at Street Level

Street-level bus stops can be provided at interchanges. For example, on diamond ramps the bus stop may consist of a widened shoulder area adjacent to the ramp roadway or may be on a separate roadway. Generally, street-level bus stops adjacent to on-ramps are preferred. Figure 4-32 shows several examples of street-level bus stops on diamond interchanges. Transit signal priority can be provided to minimize the time spent off-line.

Figure 4-32 (A) illustrates two possible locations for a bus stop at a simple diamond interchange without frontage roads. The bus stop can be provided on either the on-ramp or off-ramp by widening the ramp. However, far side stops are preferred since they are removed from ramp exiting movements and conducive to traffic signal priorities. Turning conflicts should be analyzed to determine the feasibility and appropriateness of either option.

Figure 4-32 (B) illustrates a street-level bus stop on a one-way frontage road at diamond interchanges, which are more transit-friendly for bus stops than most other interchange designs. Buses use the off-ramp to reach the surface level, discharge and load passengers at the cross street, and proceed on the on-ramp. Added travel distance is minimal, and, where traffic on the cross street is light, little time is lost. However, where cross-street traffic is heavy and buses are numerous, operation may be difficult because buses must



Not to Scale

Figure 4-30. Freeway Interchange Bus Stop Using a Driveway (*10*)

weave with the frontage road traffic to reach the stop, then weave again on the on-ramp. Highway planners should attempt to accommodate transit in planning and designing freeway interchanges.

Rather than attempting to accommodate conflicting demands at a busy interchange, it may be more appropriate to group park-and-ride, carpool parking, local-express transit interface and walk-in transit facilities at a single dedicated off-line station linked with a bus/HOV lane. The off-line station may connect to the dedicated lane on a direct ramp or slip ramp from a general purpose lane. The provision of a direct ramp requires cost-effective justification from significant demand levels, often provided by a large multi-purpose parking lot. The location of an off-line station may also have bus service and routing implications.

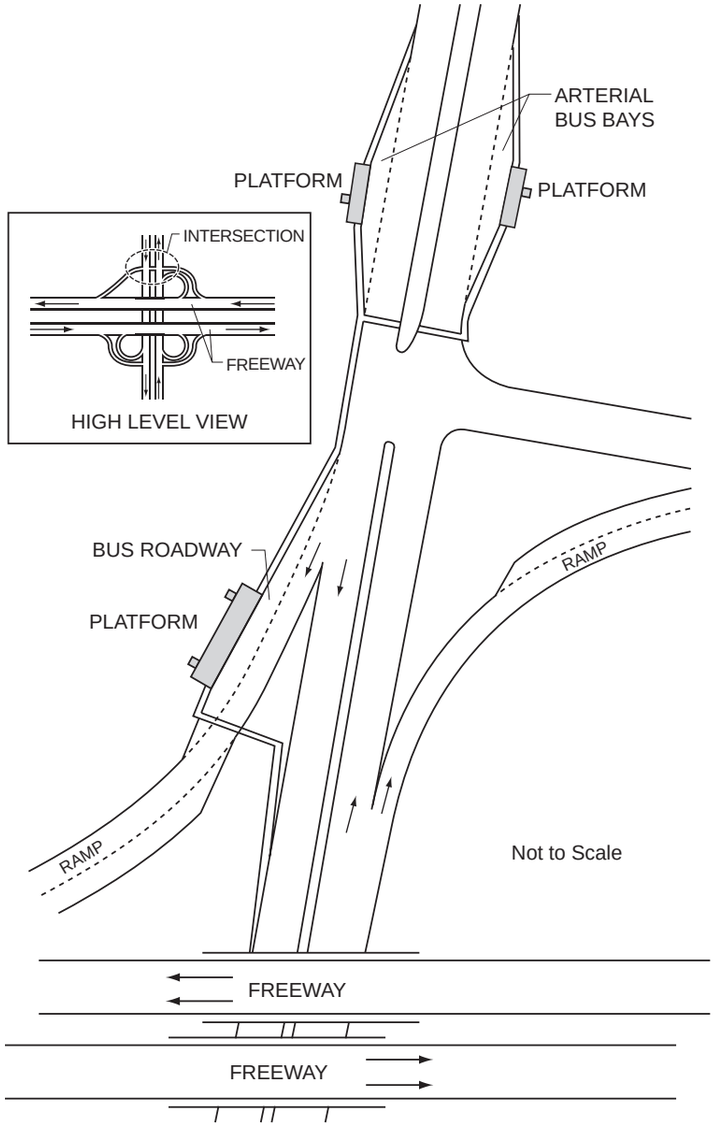


Figure 4-31. Freeway Interchange Bus Stop Using a Driveway (*10*)

4.3 OPERATIONAL REQUIREMENTS

4.3.1 Enforcement Provisions

Enforcement areas associated with the various types of bus facilities on freeways and busways must be designed to supporting facility operational integrity. Bus facilities should be designed to be enforced safely and effectively. The safety of enforcement personnel should be paramount in the design and should incorporate their input. Experience indicates that poorly designed and unsafe enforcement areas will not be used or enforced.

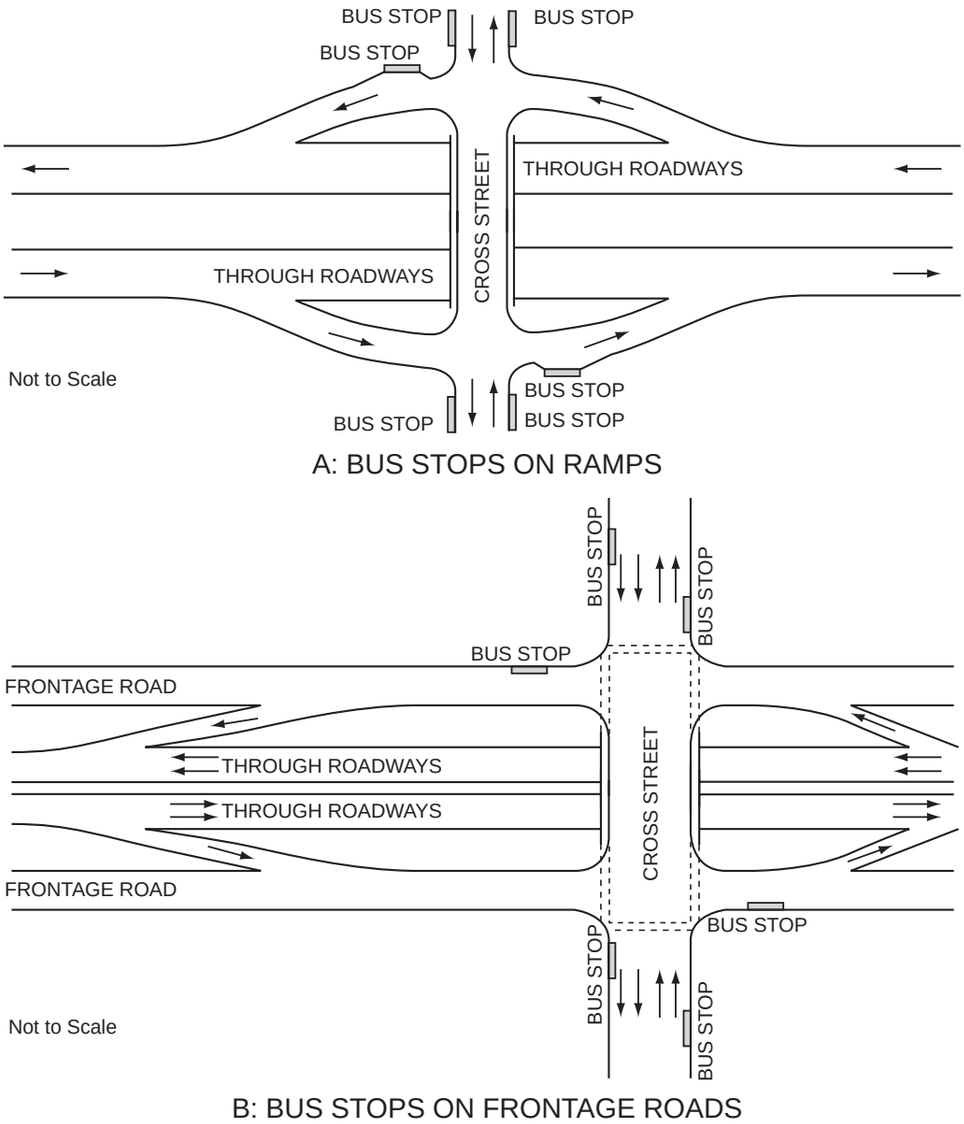


Figure 4-32. Bus Stops at Street Level on Diamond Interchange (*2*)

Designs should address various enforcement techniques including stationary, roving team, and multi-purpose patrols; remote electronic monitoring; and self-enforcement programs. The type of bus or HOV facility and specific local issues will affect the ease or difficulty of enforcement. Each type of facility and operation has different enforcement needs that require different design provisions. Table 4-8 lists some of the attributes associated with enforcing different types of bus facilities.

Busways in separate rights-of-way and barrier-separated facilities generally are easier to enforce than other facilities because of the limited and controlled access points. Contraflow and reversible lanes and queue bypasses may be enforced through a single strategically located monitoring area.

Table 4-8. Enforcement Attributes Associated with Different Types of Bus/HOV Facilities

Type of Facility	Preferred Enforcement Provisions	Minimum Enforcement Considerations
Reversible	• Enforcement areas at entrances and exits	• Enforcement areas at entrances or exits
Barrier-Separated Two-Way	• Enforcement areas at entrances and exits	• Enforcement areas at entrances or exits
Concurrent-Flow (not physically separated)	• Continuous enforcement shoulders with periodic barrier offsets • Continuous right-side shoulders	• Periodic mainline enforcement areas • Monitoring areas • Continuous right-side shoulders
Contraflow	• Enforcement area at entrance • Continuous shoulder for enforcement	• Enforcement area at entrance
Queue Bypass Treatments	• Enforcement area on right-side shoulder • Continuous right-side shoulder • Duplicate head facing enforcement area	• Enforcement monitoring pad with continuous right-side shoulder downstream

General Enforcement Design Considerations

The term "enforcement area" refers to a number of potential design treatments that provide space for police personnel to monitor a bus facility, to pursue and apprehend violators, and to issue a ticket or a citation. Space adjacent to a dedicated lane is required for these functions. Enforcement areas should be designed to account for a variety of enforcement strategies. On barrier-separated facilities (either reversible or two-way), enforcement actions usually are performed near the entrance or exit ramps where traffic is often moving slower.

The enforcement area can serve as both a monitoring and apprehension site. For concurrent flow lanes, enforcement areas may allow officers to monitor traffic, with the apprehension of violators occurring at a downstream location, which may be another enforcement area or a wide left or right shoulder. Video surveillance may be applied to identify potential violators. Enforcement of bus lanes should include both fines and towing.

Two general approaches are often used for enforcement areas. Each relates to the amount of separation or lack thereof. The two approaches are (1) low-speed enforcement areas at entrance and exit ramps, and (2) high-speed settings along the bus lane.

- **Low-Speed Enforcement Area.** Low-speed enforcement areas often are designed to provide for monitoring, apprehension, and citing of violators, and where practicable, violator removal from the bus/HOV facility. The following design features should be applied for low-speed enforcement areas:
  - The enforcement area should be at least 30 m (100 ft) long, preferably up to 60 m (200 ft) long on high-volume facilities, not including the approach and departure tapers.
  - The enforcement area should be at least 4.2 to 4.5 m (14 to 15 ft) wide.
  - The enforcement area should have an approach taper of 2:1, or 9 m (30 ft).
  - The enforcement area should have a departure taper of 10:1 or 45 m (150 ft) to allow for acceleration into the lane.

- **High-Speed Enforcement Area.** If a dedicated lane includes high-speed (75 km/h [45 mph]) or higher at-grade access locations or lacks continuous shoulders wide enough for enforcement, planners should consider periodically spaced enforcement areas. These areas are typically designed for monitoring traffic or for monitoring and apprehending violators. Planners should consider the following features in the design of high-speed enforcement areas.
  - The length of a high-speed monitoring area should be at least 30 m (100 ft), not including the approach and departure tapers. For monitoring and apprehension, the length should be preferably 390 m (1,300 ft).
  - The enforcement area should be at least 4.2 to 4.5 m (14 to 15 ft) wide.
  - The enforcement area should have an approach taper of 20:1 and departure taper of 80:1 or higher, or controlled by general freeway criteria as required to fit in the design for proper acceleration to the design speed.
  - Enforcement areas should be provided at minimum interval of 3.2 to 4.8 km (2 to 3 mi) along the mainline HOV facility.

Enforcement Design Considerations for Freeway Concurrent Flow Lanes

Concurrent flow lanes provide no physical separation from the adjacent freeway lanes. Consequently, they are the most difficult type of facility to enforce, since violators can merge in and out at will. The perception of enforcement is important in managing violations on these facilities.

Wide, continuous shoulders are used in many areas for enforcement. Where full shoulders are not available, planners should consider median enforcement areas at regular intervals. Spacing typically is 3.2 to 4.8 km (2 to 3 mi). Enforcement areas should meet the guidelines defined previously for high-speed conditions. Augmenting the entrance areas with continuous outside shoulders along the freeway is also beneficial. A sufficient length should be provided to pull over and cite a violator and to allow the violator to safely re-enter the traffic stream.

The minimum length required for this operation is roughly 390 m (1,300 ft), excluding tapers. Other desirable features include an offset in the barrier to provide protection for the officer while monitoring traffic, a median opening that allows the officer to observe both directions of traffic, lighting, and removal of any glare screen on the barrier in the affected area. The opening is particularly beneficial for motorcycle officers who can maneuver within the median opening. The enforcement area should not be signed or otherwise draw attention to its function, but it may require extra illumination.

Figures 4-33 and 4-34 show example cross-sections of enforcement areas for a reversible barrier and two-way buffer separated lanes. Figure 4-35 provides a layout of a bidirectional enforcement area created along a freeway by adjusting the median barrier from the typical section.

Potential Uses of Technology

Design efforts relating to bus lanes enforcement should also incorporate state-of-the-art technologies, including intelligent transportation systems. TCRP Report 90 on planning and implementation guidelines for bus rapid transit identified potential technology-related enforcement items.(*19*) Examples include the following:

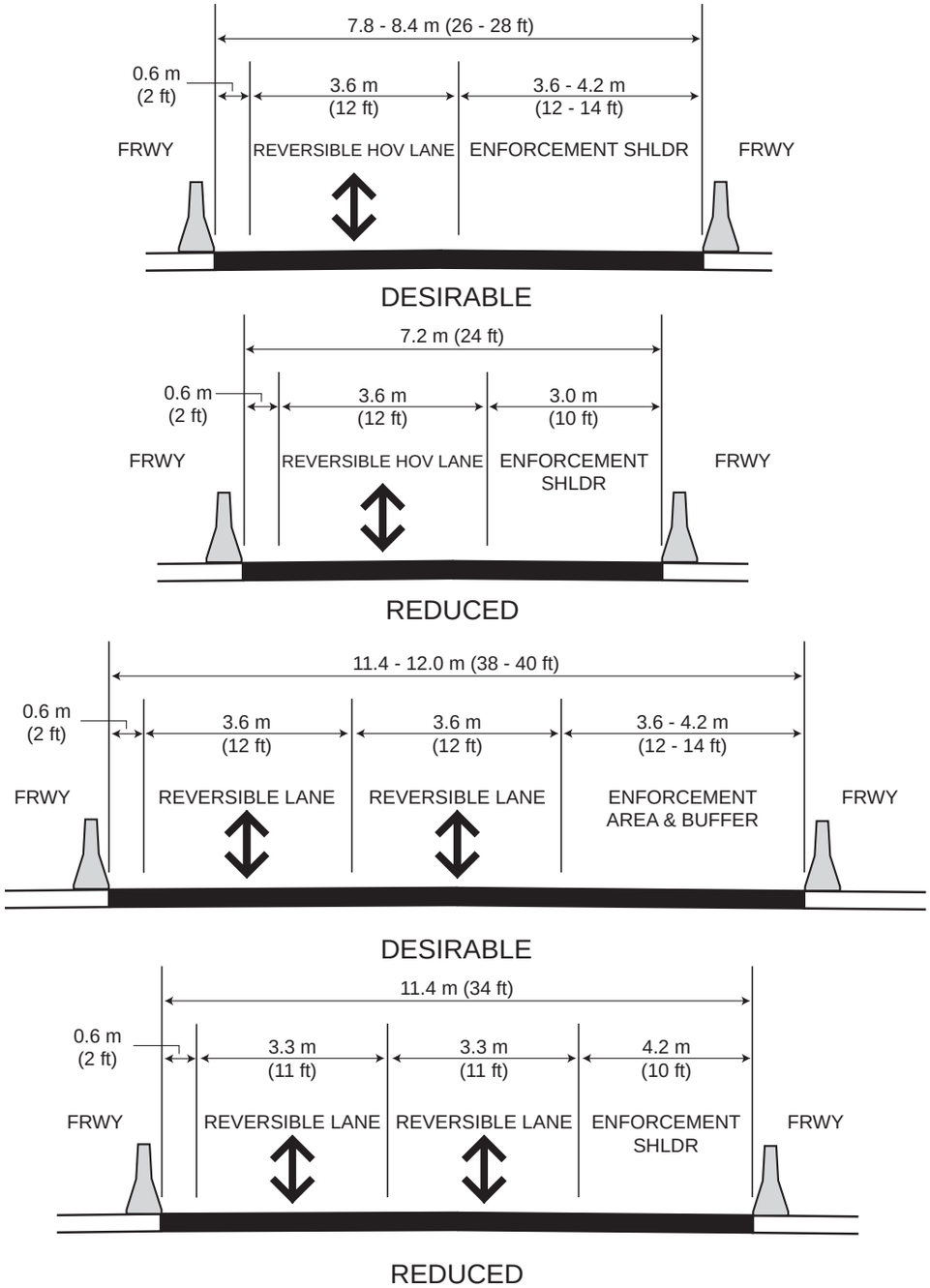


Figure 4-33. Cross Sections of Enforcement Areas on Reversible Lanes (*12*)

- A pilot system in Dallas, the HOVER system, showed promise by using a combination of automatic vehicle identification, video cameras, and infrared machine technologies.
- Portland, Oregon, has conducted an operational test of automatic vehicle identification, whereby registered carpools and buses are issued vehicle identification cards that are read at entrance ramps.

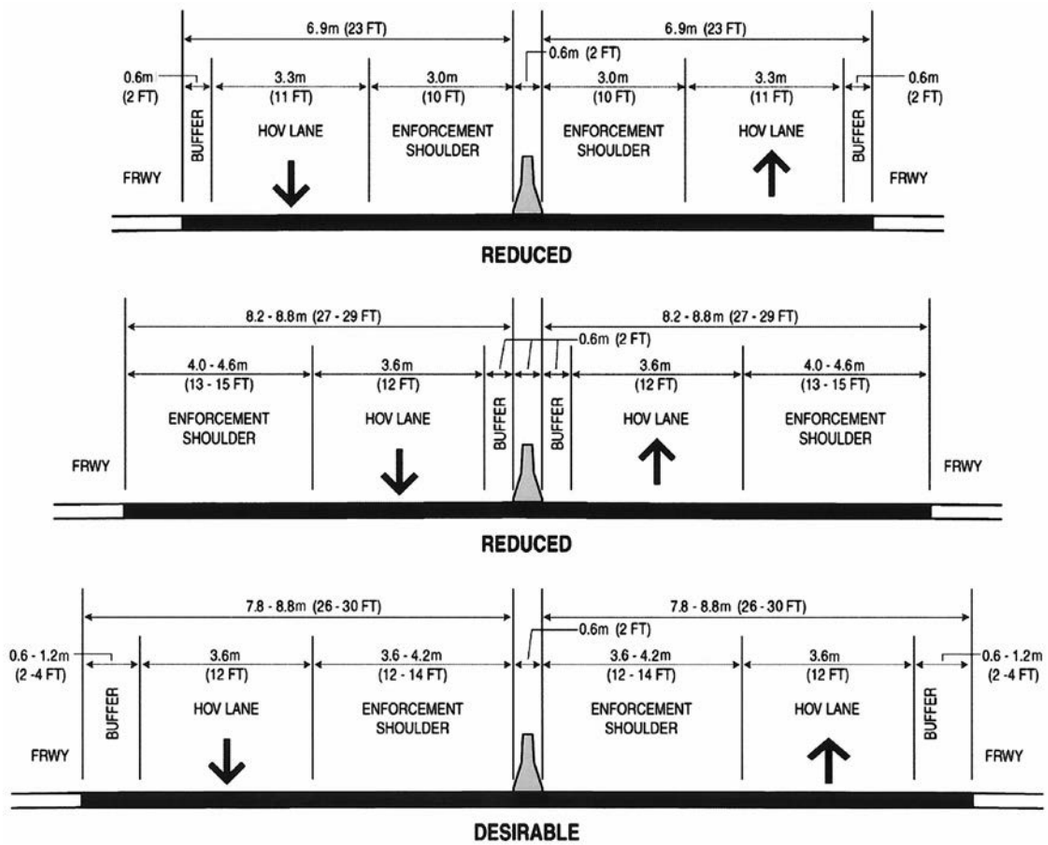


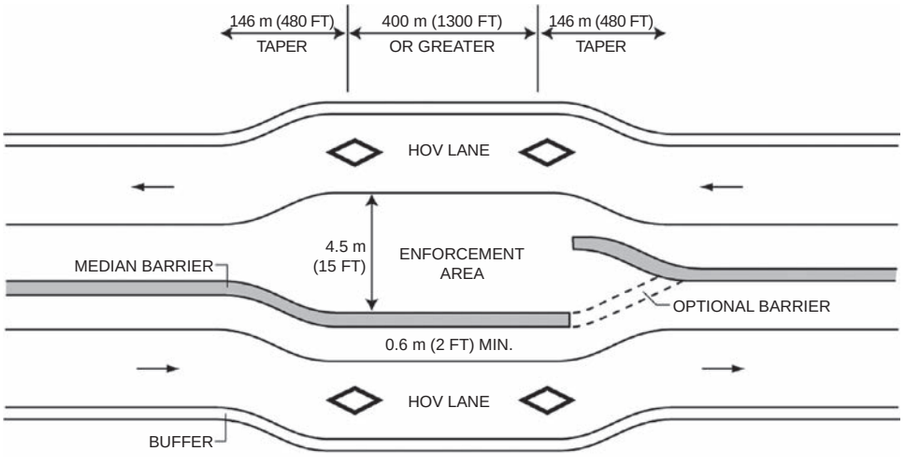
Figure 4-34. Cross Sections of Enforcement Areas on Concurrent-Flow Buffer-Separated Lanes

- Northern Virginia and California apply various audio and video techniques to detect violations and then issue citations by mail.
- Various research agencies in the United States, Canada, and United Kingdom have investigated technologies aimed at determining the number of occupants in a vehicle remotely to more effectively monitor eligibility.

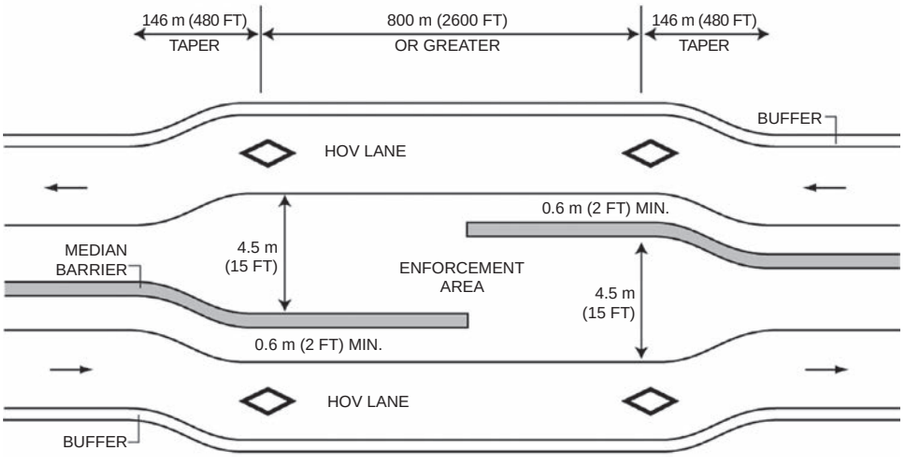
These strategies are mainly applicable on busways and freeway bus/HOV lanes. Use of colored pavements (green in New Zealand and Ireland, yellow in Brazil and Japan, maroon in France) has helped enforcement. (*3*)

4.3.2 Signing and Pavement Markings

Providing a standard set of symbols, signs, and pavement markings for bus facilities is important to building public awareness, understanding, and acceptance. Adequate regulatory and guide signs are critical for both users and non-users. Signing also plays a key role in public education and enforcement strategies. Planners should use the *Manual on Uniform Traffic Control Devices* (MUTCD) in designing and locating



Directional Enforcement Area



Bi-Directional Enforcement Area

Figure 4-35. Directional and Bi-Directional Enforcement Area Layout (*12*)

signs and pavement marking for bus facilities on freeways and in separate rights-of-way. Section 2G, Preferential and Managed Lane Signs, and Section 3D, Marking for Preferential Lanes, relate specifically to bus facilities. Other sections of the MUTCD in the latest edition address several other types of signs and markings commonly used with transit projects, along with example layouts of common interchange treatments. (*6*)

Many traffic control signs and pavement markings used on bus-only facilities are similar to those found on freeways and roadways. For example, common pavement markings may include flush median delineation, solid yellow center or left shoulder lines, solid white pavement edge lines, and turn-lane arrows and lane lines. Freeways and bus/HOV facilities share many common signing and pavement markings, but many unique elements are associated with signs and markings on bus-only projects.

Regulatory and Guide Signs

The MUTCD along with state guidelines should be used in the design and placement of signs associated with bus facilities. The following general applications govern regulatory and guide signs.(*6*)

- Regulatory signs should use the standard black lettering on a white background. A diamond symbol on signs and pavement markings are reserved for HOV lanes. A diamond symbol may be used by a transit facility if it is shared with an HOV facility. Use of a diamond symbol should be considered to help build awareness and to reinforce the special nature of HOV facilities. Placement positions for the diamond are optional. Sign clutter can be avoided in some instances if regulatory information is contained within some guide sign applications. Bus/taxi lane regulatory signing on urban streets does not require the application of the diamond symbol on signing or pavement markings.
- The size of a sign should be related to its location and the design speed of the facility. The same guidelines on letter size used with other highway signs should be followed with transit signs.
- Signs relating to bus lane restrictions, including operating hours, should be provided at regular intervals along the facility. Overhead or side-mounted signs have specific applications, and consultation with the MUTCD is advised.
- Additional signs should be considered at all access points, as well as in advance of the beginning of a bus lane. Signs should be provided in advance of access points to alert users and non-users of the approaching ingress and egress. Static and changeable message signs may both be used where operating periods and user eligibility change by time of day. Charging tolls on such lanes further provides justification for dynamic messages to signs.

Figure 4-36 shows examples of regulatory and guide signs.

Figure 4-36. Examples of Regulatory Signs Used with Bus/HOV Facilities (*6*)

Figure 4-37. Example of HOV Lane Pavement Marking (*12*)

The use of a white diamond symbol painted on the pavement commonly denotes dedicated HOV lanes. The 2009 edition of the MUTCD reserves this symbol for HOV lane use only.

Figure 4-37 provides an example of pavement marking used on an existing HOV facility. Planners should consider the pavement markings in enforcement areas. Special striping or other techniques should differentiate the enforcement area from the bus/HOV and general purpose lanes.

The 2009 edition of the MUTCD contains details on barrier-separated, buffer-separated, and contiguous preferential pavement markings. Table 3D-1 from Section 3D of the MUTCD (shown here as Table 4-9) provides the requirements of longitudinal markings for preferential lanes. (*6*)

Signing Within Freeway Bus Stations Areas

Signing, markings, and other traffic control design devices (e.g., rumble strips, flashing beacons, pedestrian push-button countdown signals, and radar-type speed signals) should be used to warn and control vehicle traffic entering a station area. It may also be desirable to include stop signs at the entrance to the station area, although this could delay buses. Crosswalks should be made as visible as possible.

4.4 PROTECTING FUTURE NEEDS

The initial planning for a new expanded facility should consider both existing and future public transportation needs and potentials. Most high-capacity bus and rail transit lines radiate from the city center; therefore, radial freeways focusing on the CBD offer the best potential for combined freeway-transit (or HOV) facilities. Except in the Los Angeles urban area, most HOV lanes are also radial. Large suburban "edge city" centers, properly designed, may also be good candidates for multi-modal facilities.

Rights-of-way for transit facilities should be reserved as necessary physical provisions made for public transport, even if the transit facilities are built at a later date. For example, wide medians or freeway envelopes could be established at the outset or when major reconstruction occurs. Often, a different agency will design the transit component. Therefore, multi-agency coordination is essential in basic corridor planning and design.

Table 4-9. Standard Edge Line and Lane Line Markings for Preferential Lanes

Type of Preferential Lane	Left-Hand Edge Line	Right-Hand Edge Line
Barrier-Separated, Non-Reversible	A normal solid single yellow line	A normal solid single white line
Barrier-Separated, Reversible	A normal solid single white line	A normal solid single white line
Buffer-Separated, Left-Hand Side	A normal solid single yellow line	• A wide solid double white line along both edges of the buffer space where crossing is prohibited, • A wide solid single white line along both edges of the buffer space where crossing is discouraged • A wide broken single white line along both edges of the buffer space, or a wide broken single white line within the buffer space (resulting in wider lanes), where crossing is permitted
Buffer-Separated, Right-Hand Side	• A wide solid double white line along both edges of the buffer space where crossing is prohibited • A wide solid single white line along both edges of the buffer space where crossing is discouraged • A wide broken single white line along both edges of the buffer space, or a wide broken single white line within the buffer space (resulting in wider lanes), where crossing is permitted • A wide dotted single white line within the buffers space (resulting in wider lanes) where crossing is permitted for any vehicle to perform a right-turn maneuver	A normal solid single white line (if warranted)
Contiguous, Left-Hand Side	A normal solid single yellow line	• A wide solid double white line where crossing is prohibited • A wide solid white line where crossing is discouraged • A wide broken single white line where crossing is permitted
Contiguous, Right-Hand Side	• A wide solid double white line where crossing is prohibited • A wide solid single white line where crossing is discouraged • A wide broken single white line where crossing is permitted • A wide dotted single white line where crossing is permitted for any vehicle to perform a right-turn maneuver	A normal solid single white line

Note: 1. If there are two or more preferential lanes, the lane lines between the preferential lanes shall be normal broken white lines.

2. The standard lane markings listed in this table are provided in a tabular format for reference.

Table 4-10. Width Required for Transit Lane Treatments (*12*)

Lane Treatment Type	Desirable	Reduced
Concurrent Flow—Buffer Separated	18.6 m (62 ft)	10.2 m (34 ft)
Concurrent Flow—Non-Separated	6.6 m (22 ft)	4.8 m (16 ft)
Barrier-Separated Two-Way—Median with Barrier	16.5 m (54 ft)	13.8 m (46 ft)
Exclusive Barrier-Separated Two-Way—With Median Shoulder	12.6 m (42 ft)	11.4 m (38 ft)
Reversible (single lane)	8.4–9.6 m (28–32 ft)	6.0 m (20 ft)
Reversible (dual lanes)	12.0–13.2 m (40–44 ft)	9.6 m (32 ft)
Busway/Separate Right-of-Way	14.4 m (48 ft)	11.4 m (38 ft)
Contraflow	6.6–7.2 m (22–24 ft)	4.2 m (14 ft)

Table 4-11. Width Required for Transit Stations

Component	Desirable	Reduced	Minimal
Side Platform	27 m (90 ft)	23 m (74 ft)	15 m (50 ft)
Center Platform	27 m (90 ft)	23 m (76 ft)	n/a

Table 4-12. Width Required for On-Line Stations

	Side Platform Stations			Central Platform Stations	
Component	Desirable	Reduced	Minimal	Desirable	Reduced
Platform	4.5 m (15 ft)	3.0 m (10 ft)	2.4 m (8 ft)	4.5 m (15 ft)	3.6 m (12 ft)
Bus Loading Lane	3.6 m (12 ft)	3.6 m (12 ft)	3.6 m (12 ft)	3.6 m (12 ft)	3.6 m (12 ft)
Through Lane	3.6 m (12 ft)	3.6 m (12 ft)	n/a	3.6 m (12 ft)	3.6 m (12 ft)
Through Lane Buffer	1.2 m (4 ft.)	0.6 m (2 ft.)	n/a	1.8 m (6 ft.)	0.6 m (2 ft.)
Center Buffer	1.8 m (6 ft.)	0.6 m (2 ft.)	3.0 m (10 ft.)	n/a	n/a
Total	27.6 m (92 ft.)	22.2 m (74 ft.)	15 m (50 ft.)	27 m (90 ft.)	19.2 m (64 ft.)

To reserve sufficient right-of-way width for future bus transit facilities, the type of future transit facility should be considered. Table 4-10 summarizes the width required for the various bus facility treatments discussed in Section 4.2. Table 4-11 describes the width required for transit stations. Table 4-12 summarizes the typical width requirements for in-line bus stations.

Where a future bus transit facility may be converted to rail transit, planners should consider appropriate design requirements for such a conversion. For example, horizontal curves for light rail may require the reservation of additional right-of-way beyond that required for a bus transit facility.

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5 Guidelines for Bus Facilities on Streets and Roadways

In This Chapter:

Most conventional urban bus services operate on city streets and suburban roadways. Most of the bus passengers carried and bus-miles operated are on these facilities. Even buses operating on limited access highways use streets in both suburban areas and in the city center to reach the freeways.

In the arterial street setting, the provision and design of transit facilities should be fully integrated with the in-street and curb-side infrastructure. Improving bus movements include both geometric designs and operational strategies.

This chapter addresses transit arrangements and treatments that most directly involve street and roadway design. It begins with general planning guidance, then provides specific guidelines for bus operations in mixed traffic, bus lanes, and busways. The chapter covers location and design of bus stops, bus bulbs, bus turnouts, and queue bypasses. It also identifies key operational issues, such as signing and enforcement.

The focus is on bus transit operations and facilities. Guidelines for HOV facilities on arterial streets are addressed in NCHRP Report 414, HOV *Systems Manual* (*27*). The discussion concentrates on the transit arrangements that most directly affect roadway design and vice versa. Buses can operate in mixed traffic or under various degrees of preferential treatment over—or segregated from—other vehicles. In mixed operations, the key transit facilities are located at the

curbside, where transit vehicles and their passengers (customers) interact. Transit preferential treatment may be provided along the curb, or in interior bus lanes, or within the center of a street. This chapter complements the design guidelines for street and light rail transit outlined in Chapter 6.

5.1 GENERAL PLANNING AND DESIGN CONSIDERATIONS

Most bus transit operates in mixed traffic on streets. Generally, ways to make traffic move faster and safer will improve bus speeds and service reliability. Roadway geometry should be adequate for bus movement, and pedestrian access to stops should be convenient. There are situations where preferential treatment for transit (dedicated lanes, stations, and priority at traffic signals) may be desirable. In those cases, the benefits to transit riders should be balanced with the effects on road traffic. The goal is to minimize overall person delay. The provision of bus transit recognizes that a single bus can carry as many commuters as 40 or 50 personal vehicles and that urban transportation systems should focus on the efficient movement of people and goods, not merely vehicles. Therefore, the general approach to planning and implementing transit facilities on streets is to recognize the role of public transit in providing mobility to both transit-dependent and "choice-of-mode" passengers within the urban transportation network, and, where appropriate, to assign a higher priority to transit operations over general traffic movement.

Treatments and priorities for bus transit can vary depending upon specific traffic, roadway, and environmental conditions. Regardless of the type of treatment, the geometric design and traffic control features should adequately and safely accommodate all vehicles and pedestrians that would use a street or road. Where a facility will be limited to buses, design features can be modified easily from those that apply for general traffic use. Designers must consider the needs of maintenance, service, and emergency vehicles in the design criteria.

At an early stage, planners and designers may be asked to consider whether it is possible to convert from general traffic or bus priority facilities to light rail transit. Some light rail design parameters differ from those for rubber-tired transit facilities. Examples include pavement depth and structure, superelevation, drainage, passenger stops, power/communications provisions, grade, and horizontal and vertical clearances. If the potential to convert to light rail exists or a bus facility is being implemented as an interim step, the design criteria should combine the governing most restrictive aspects of both bus and light rail modes (see Chapter 6).

5.1.1 Policy Context

Many policies influence the design of facilities for transit vehicles along arterial streets. These policies are established by the transit agency, street and road agency, and/or city planning agency. The general objectives of these groups are to improve transit speed and reliability, improve safety, maintain effective levels of service for general traffic, support urban development, and enhance the environment. Transit policies include when, where, and how the service is or will be provided. Key elements include service type, coverage, span, frequency, route design, and stop spacing, cost recovery requirements, fare collections methods, vehicle type, door configurations, and lift location.

Transit Policies

Route Design/Type of Service

Bus route design can affect bus operations. Typical route design includes express, line-haul, and local/feeder. Express bus service usually follows higher type streets and is generally routed to minimize the

number of turns so that higher travel speeds are obtained and passenger discomfort from shifting of the vehicle is minimized. Stops occur at major intersections or significant land uses at spacing usually greater than 500 m (1,680 ft). Bus rapid transit service is similar to express service and may have higher levels of preferential treatment, including exclusive lanes. Line-haul service generally follows a major arterial with few to no turns and more frequent stops than with express service. Local bus routes run at slow speeds, with standard or small buses, and may meander through residential neighborhoods on smaller streets.

Service type may affect bus stop design and operation. A station used by an express service may need longer platforms for queued buses and possibly wider platforms to accommodate higher numbers of waiting passengers than one serving local buses. As a premium service, express bus routes often have higher levels of support amenities, such as shelters, benches, and landscaping, which require additional area and consideration of the interaction of different design elements such as landscaping and impacts on underground utilities. Express stations can act as hubs for local bus routes, creating transfer centers. While local buses circulate through neighborhoods, express buses minimize the number of turns and are given priority to reach higher speeds. Express routes are often operated with articulated buses or highway coaches that have different operating characteristics than standard city buses. Most notably, highway coaches make considerably wider turns and require larger curb radii.

Frequency of Service

In corridors with high ridership, bus service offered at higher frequencies is possible. Priority lanes may be appropriate to decrease travel time if bus traffic is being delayed because of general roadway congestion or long dwell times for boarding/alighting passengers. With high frequency of service or multiple routes, more than one bus may be at a stop or platform at any given time, resulting in a need for longer stops/platforms.

Number of Routes

The number of routes running on a street and using a stop will affect the stop design. Platform length may need to be increased to accommodate platoons of buses. A longer platform may have to be situated in locations that will not severely affect existing on-street conditions. When many routes run on the same street, one or more routes may act as an express and only service a few of the stops. A street serving many bus routes might be a candidate for bus priority lanes and signal pre-emption.

Fare Policy

The method of fare payment influences the time that a bus is stopped and therefore the design and size of stops. Advance payment will decrease stop time by eliminating delays associated with on-vehicle payment and by allowing multiple door boarding. This can reduce the space required for waiting areas but may require longer platforms to take advantage of multiple door boarding and also a method for advance payment. Electronic fare machines installed at stations allow payment with credit and debit cards. Bus stop design considerations should include the area and location for the fare machines, power and communication needs, and pedestrian circulation in the immediate area.

Peak and Off-Peak Service

The peak demand characteristics of transit service and roadway conditions, including time and direction, influence design decisions. Peak-period traffic conditions tend to be congested, and bus service often is designed to serve peak-period trips. As with roadways, transit service design decisions often focus on peak

periods, and priority measures can be tailored accordingly. Peak-period priority measures can include reserved peak-period bus lanes that serve as parking in off-peak times, and signal priority that operates during the peak. The high frequency of buses usually associated with peak-hour service may require longer platforms. Off-peak conditions for transit tend to be more important than for general traffic as the speed and reliability of transit routes throughout the day can affect the perceived quality of service and ridership.

Vehicles

A wide array of transit vehicle types is offered by manufacturers. The choice of the "design vehicle" can be important as variations occur in lengths, turning characteristics, number and location of doors, and accessibility. In addition, bicycle racks and propulsion systems also influence design. The choice of the design vehicle must balance the existing roadway geometry and the need to maintain future operating flexibility and capacity by not constraining the operating environment, while guarding against the danger of "over-designing" a facility with associated financial costs and community impacts.

Articulated buses are about 6 m (20 ft) longer than standard city buses and require commensurately longer platforms. Platform lengths may need to accommodate bike racks and the extra clearance for its operation. Turning radius for bus transit vehicles generally increases with bus size, with the exception for articulated buses, where 18 m (60 ft) articulated buses have turn characteristics comparable to standard city buses. Highway coaches have greater turn radii compared to similar-sized city buses.

Platform or stop design should consider the number and location of doors. Whereas buses typically have a front and side door, articulated buses can have three doors, and rapid transit type buses may have doors on both sides.

The choice of propulsion for a vehicle can also influence design. Trolley buses, for example, are limited to specific routes and have specific infrastructure requirements. Diesel propulsion may be an issue in tunnel situations, although this is being overcome by hybrid technology. Alternative-fuel options may have specific fueling or charging facility requirements, or operational limitations such as on steep slopes.

Urban Design and Planning

Transit facilities not only serve the traveling public, but also shape the community where they are located. Increased street width and corner radii are major determinants in the quality of the pedestrian environment and the feel of urban spaces, but they must be adequate for transit vehicles and general traffic. The distance between stops can influence the character of an area (and vice versa). Frequent stops can result in pedestrian activity along the length of a street, whereas less frequent stops associated with express service can create pockets of activity. Stop locations not only should be chosen to serve the travel demand of adjacent uses. They should be located to tie into nearby developments. Shelter design should be distinctive and should fit the overall urban plan for a community.

Non-Transit Policies

Intersections

The configuration of an intersection and the surrounding built environment determine how well transit service is accommodated. Policies affecting intersection geometry determine how well a bus can navigate intersections. Channelization or the ability to prohibit right turns may influence the location of transit stops and the type of transit priority chosen. If the island created by the channel is long and wide enough, a stop can be located there. Far-side stops eliminate conflict with right-turning vehicles channeled from the

same approach but may conflict if there is traffic from other directions merging where the stop is to be located. Far-side stops do not block the view of the crossing pedestrians from vehicles in the adjacent lanes.

Lane widths, curb radii, the presence of roundabouts, curb heights, and sidewalk widths are other variables that should be established. Access control policies are important since driveways should not be located at bus stops. Stops should be located for convenient access without being in conflict with access points to adjacent land uses. Sight lines at intersections may affect the stop location or type of passenger amenities.

Traffic Signals

Policies relating to traffic signals and LOS can become very complex where the traffic engineers address the various user needs—prioritizing multiple-user demands including general traffic, pedestrians, cyclists, commercial traffic, buses, emergency vehicles, and light rail transit. Overall operating policies, such as minimizing vehicle delay, person delay, or transit delay, should determine the level of transit priority that can be achieved and whether it is active or passive. Pedestrian crossing distances and resultant clearance intervals may influence decisions on stop locations in the centers of wide streets. Along wide streets, the provision of reserved lanes can enhance transit service but may adversely affect pedestrian access to the stops because of the increased crossing distances. Green time and progression can influence choices on both the number of stops and location of stops at intersections. To take advantage of the signal progression, fewer stops on the far side of the intersection may be attractive.

Bicycles

Policies related to bicycle facilities affect transit in a number of ways including:

- Viability of shared transit and bicycle reserved lanes
- Tradeoffs between on-street bicycle facilities and transit priority measures
- Platform design including space for bicycle parking
- Length of platform for loading of bicycle racks

Tradeoffs that must be considered when allowing bikes in bus lanes are that bus speed may be limited by bike speed at times, conflicts may occur between bicyclists and loading or unloading bus passengers when bike lanes are along the curb, and conflicts between buses and bikes when bike lanes are between bus lanes and general travel lanes.

On-Street Parking

On-street parking policies can affect the type and feasibility of transit priority and location of stops. Reserved curb space can be created by prohibiting parking at the near or far side of an intersection. Parking may be allowed during the off-peak period, whereas during peak periods the lanes could be used as priority lanes. Elevation of platform and location of on bus bicycle storage (front or underneath) will affect bicycle loading.

Mid-Block Access and Loading

Designers need to consider mid-block access and loading and the timing of these activities. Loading activities may detract from transit priority as vehicles may park in front of the bus or may be queued in

the curb lane. Consider pedestrian crossings near the bus stop. Refer to Chapter 7 for more guidance on pedestrian and bicycle access.

5.1.2 Relating Bus Facilities to Adjacent Land Uses

Transit service in the urban street environment should be closely coordinated with the surrounding developments. Each should support the other in making communities more livable and in enhancing transit ridership.

Eight general principles contribute to transit friendly development:

- Achieving appropriate community densities;
- Developing mixed-land uses;
- Employing transit-oriented site design;
- Routing transit into the community;
- Minimizing walking or cycling distance;
- Creating a bicycle and pedestrian friendly environment;
- Reducing transit travel time; and
- Building quality, user-friendly transit facilities (*32*).

This section discusses the first four principles on this list from the perspective of providing transit service to an existing development. The other four are discussed elsewhere in the guide.

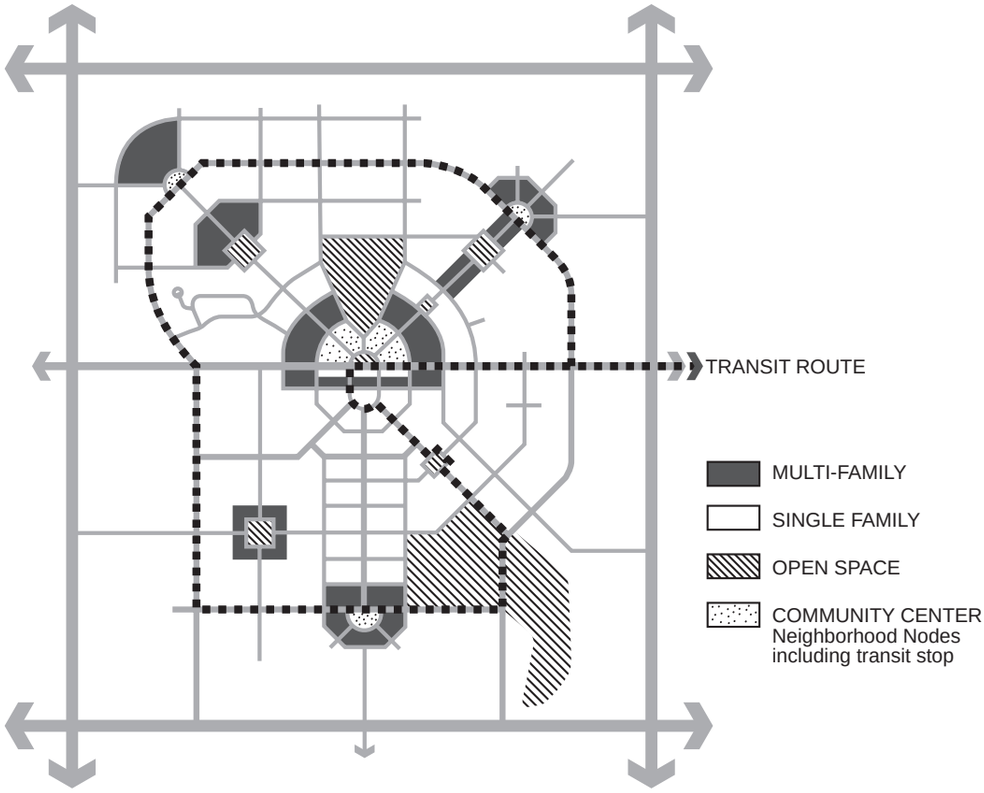
Appropriate Community Densities

Population density directly affects the quality (frequency of service), range (service choices), and duration (hours of operation) of transit service that can be operated in an area. Community densities that support the efficient delivery of transit service have a floor area ratio of no less than 0.25 but preferably in the range of 0.5 to 1 for commercial development. Floor area ratio is the ratio of the total covered area of all floors of a development to the area of the plot of land where that development is located. For resident development, six to eight units per acre is typically considered a minimum, with higher density of 12 to 16 (multi-family) housing being preferable.

High employment densities in the CBD and other outlying activity centers contribute to high transit ridership. CBD employment of more than 100,000 concentrated in a rather dense area can support rapid transit.

Mixed Land Uses

Mixed land uses support efficient transit operations by concentrating different destinations in one area and by allowing for linked trips. Trips can be linked where transit riders can accomplish a number of tasks in a small area either by walking (as from work to a drycleaner, then returning home by bus) or by using line-haul type service where one can get on and off easily along a commercial strip. Mixed land uses include residential, office, retail, and services such as dry cleaners, convenience stores, daycares, and libraries. The layout of "big-box" or large discount stores tends to be more auto-oriented and generally less appropriate at transit stations and bus stops (*33*).



Source: Draft Transit Friendly Design Guide, Calgary Transit, p. 10.

Figure 5-1. Density Organized to Benefit from Transit (*2*)

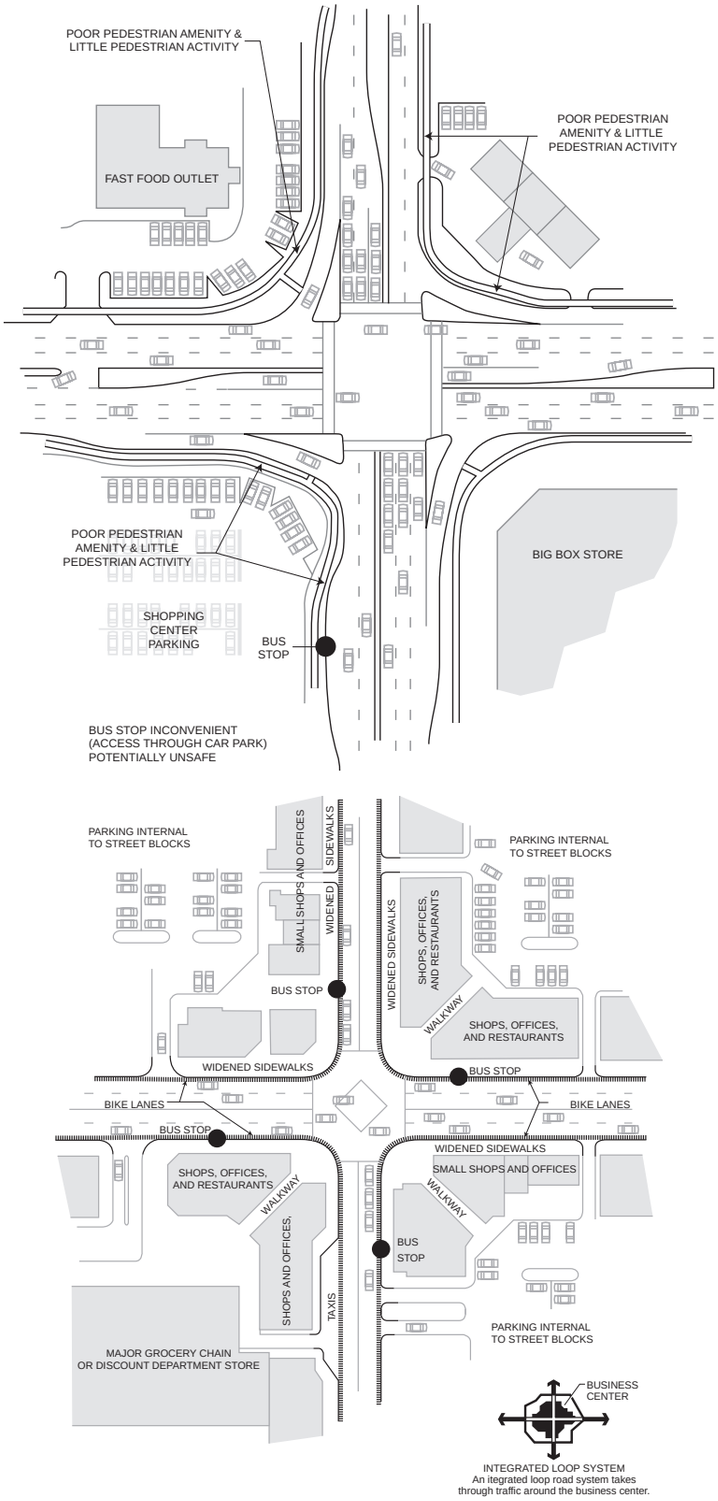
Transit-Oriented Site Development

Transit services can be routed to serve higher density areas and to link these areas with major employment and commercial centers. Figure 5-1 shows how transit routes can converge in a community center surrounded by multi-family dwellings. The clustering of activities along bus stops creates a pedestrian-friendly urban environment by reducing walking distances and bringing various activities within a short walk from the stops. When street traffic conditions permit, roadways can be narrowed to further improve walking conditions and access to bus stops. Figure 5-2 compares a typical vehicle-oriented development pattern with a development pattern of commercial density clustered and organized around transit stops.

When locating transit stops, short, direct walking distances between buildings and transit service is preferable (Figure 5-3). Whenever possible, stops should be located away from walls, beams, or steep slopes that isolate buildings from the stop. Landscaped areas can provide shade, a buffer from traffic, and visual interest, but they should not be located in such a way as to increase walking distances to transit stops. Bus routes are more effective when they are adjacent to a building, not a parking lot.

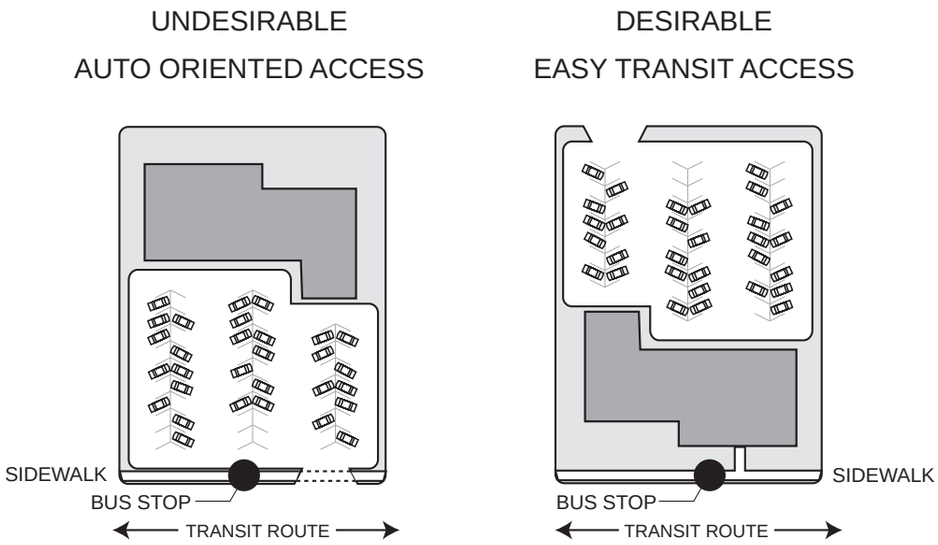
Route Transit into the Community

Transit should be integrated into the heart of a community or development. Bus routes should be located with development on both sides of the route to increase the number of people benefiting from the service. Figure 5-4 illustrates vehicle- and transit-oriented development arrangements.



Source: Accommodating Alternative Transportation Modes in Site Planning–Next Steps

Figure 5-2. Density Organized to Benefit from Transit (*41*)



Source: Draft Transit Friendly Design Guide, Calgary Transit, p. 12.

Figure 5-3. Transit Route Access to Building (*2*)

5.2 BUS STOP LOCATIONS AND DESIGN

Bus stop location and design along arterial streets influences transit operations, intersection capacities, and pedestrian safety. Street-side stops enable buses to serve passengers conveniently and to be through-routed without the time losses associated with bus terminals.

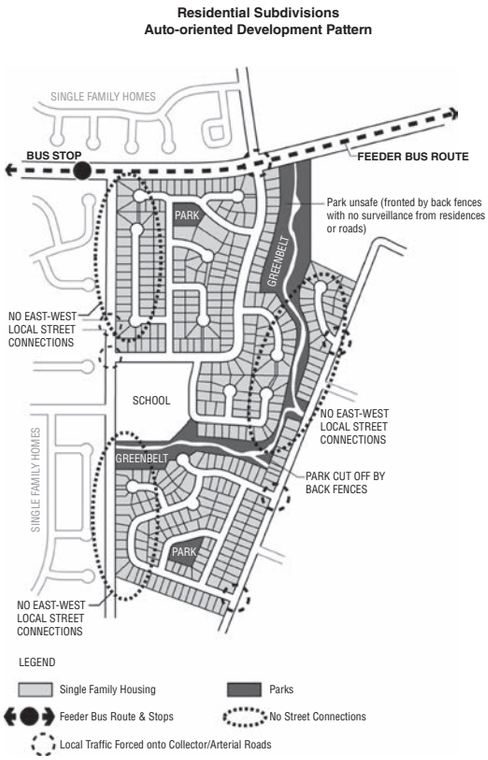
5.2.1 General Guidelines

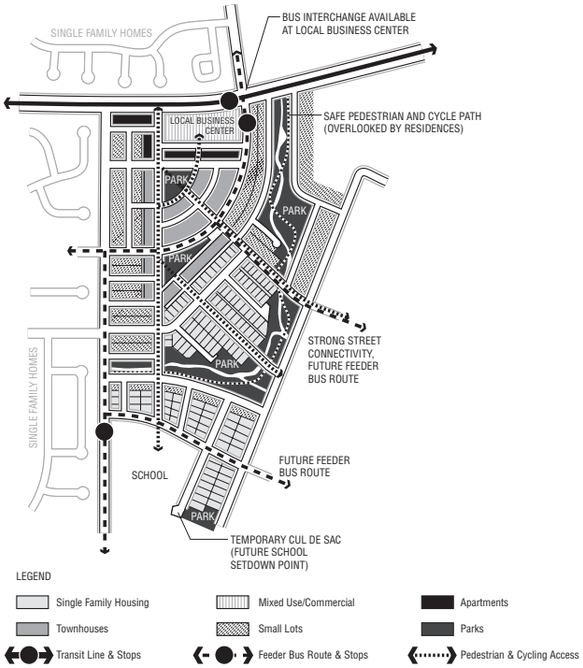
This section describes the features and presents the layouts for the three primary types of bus stop treatments:

- **Curbside stops** are used on all types of roads and streets. Parking may be permitted or prohibited.
- **Bus bulbs** are appropriate along urban streets where parking is permitted at all times. They are applicable in urban settings with frequent transit services and considerable pedestrian movements, traffic flows are light, and speeds are low, usually under 65 km/h (40 mph).
- **Bus bays** are appropriate along roadways where the curb lanes are used by moving traffic and speeds are higher, usually over 65 km/h (40 mph).

Stop Spacing and Location

Stop spacing and location principles have evolved over time and are often a carryover from street railway operations. Stops should be placed near areas of high passenger trip generation, such as office buildings, schools, medical centers, and apartment complexes. They should also be placed at locations where they connect with other transit lines and major cross-streets. The spacing of bus stops should reflect





Source: Accommodating Alternative Transportation Modes in Site Planning–Next Steps

Figure 5-4. Transit Routes and Subdivision Development

development density, street patterns, and the type of service operated. Stops generally should be less than 120 m (400 ft) apart in CBDs, and 200 m (660 ft) in urban areas. Spacing in suburban areas should range from 200 to 400 m (660 to 1,320 ft). Stops for limited stop or bus rapid transit (BRT) service generally should be spaced at 0.8 to 1.6 km (0.5 to 1.0 mi).

Patronage and the locations of intersecting bus routes and transfer points generally govern the locations of bus stops. Convenience and safety are essential. Bus stops usually are located curbside: (1) far-side, where the bus stops immediately after an intersection; (2) near-side, where the bus stops immediately before an intersection; and (3) mid-block, where the bus stops in the middle of the block between intersections. Stops may be placed alongside interior and median lanes for certain types of priority treatments. They also may be placed along sidewalk extensions (bus bulbs) or in recessed bus bays.

Pedestrian Access

Pedestrian access from the catchment areas surrounding bus stops should be convenient, direct, and safe. Connecting streets should be used where available. In other cases, pedestrian connection between bus stops and surrounding neighborhoods should be provided. Figure 5-5 shows an example of pedestrian links to bus stops.

Bus Stop Lengths (Capacity)

Bus stops should be long enough to accommodate the likely number of buses that would use them at any given time during peak periods. The number of berths needed depends upon peak bus flow rates, dwell times at stops, and the acceptable likelihood of failure (that is, the likelihood that buses will need to queue over a longer distance than the bus stop will accommodate). Table 5-1 lists the approximate number of berths that should be provided at signals. These data reflect a five percent failure rate. Thus, for 60 buses per hour, with a 30-second average dwell time, two berths should be provided.

On-street stops are linear: the first bus to arrive occupies the first loading area, the second bus occupies the second loading area, etc. Each additional loading area is less effective than the one before it for three reasons:

- Depending on how closely buses stop behind the bus in front and the buses' ability to pass each other, a bus may not be able to leave its loading area until the bus in front departs (*38*).
- Passengers may have to walk farther to board buses or may expect the back bus to make a second stop at the front of the line.
- Capacities of successive berths are less than for off-line stops where bases have independent arrivals and departures (*25*).
- Chapter 3, Appendix D, of the *Transit Capacity and Quality of Service Manual* (*38*) contains detailed procedures that account for different failure rates and the decreased effectiveness of multiple berths.
- Yield-to-Bus Laws

Re-entry delays associated with buses merging back into traffic from a curbside bus bay can be countered by implementing and enforcing a yield-to-bus (YTB) law. These laws were applied in Europe during the 1970s to provide transit vehicles priority when leaving a stop (*17*). California, Florida, Oregon, Washington, British Columbia, and Quebec have similar laws. Motorists are reminded of the law by a sticker mounted on the back of the bus or by a flashing signal.

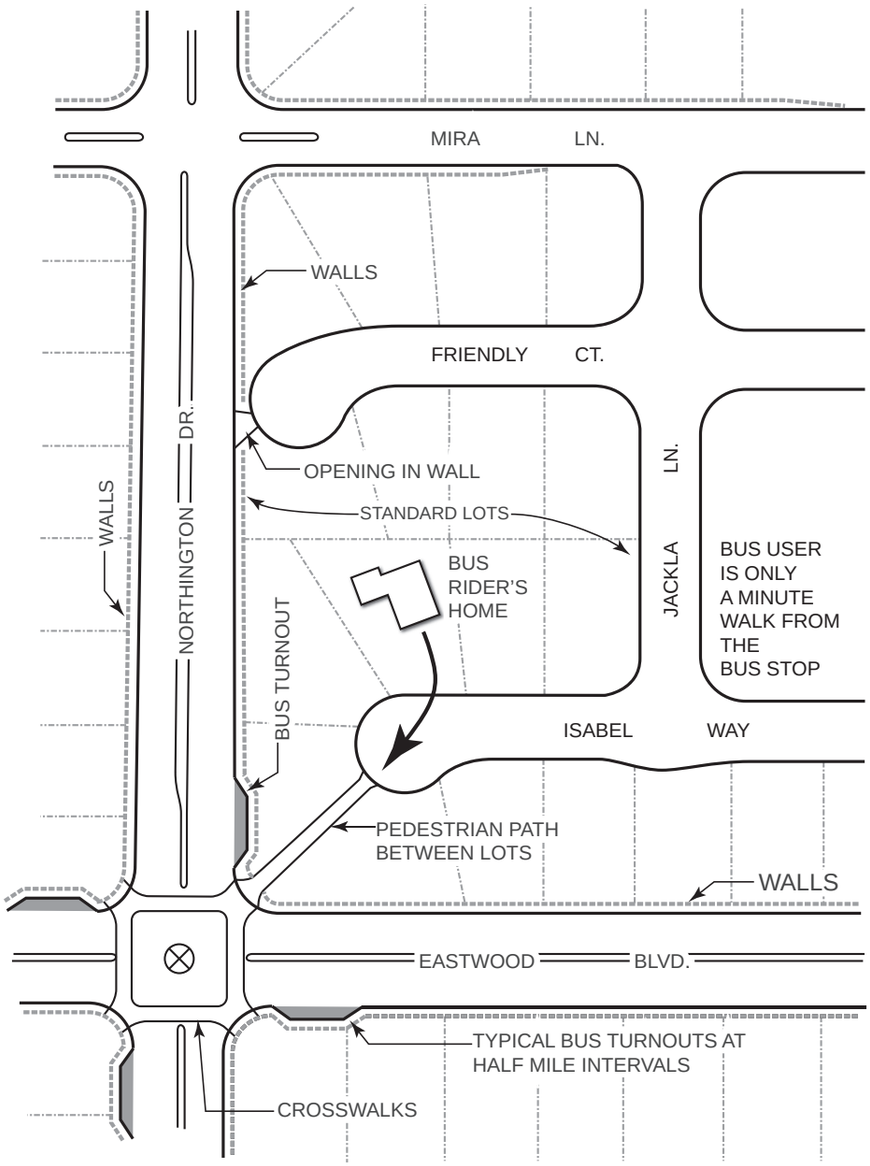


Figure 5-5. Pedestrian Links to Bus Stops

No quantitative benefits in time savings associated with these lanes have been reported. However, agencies indicated that more time savings were obtained where the speeds were generally less than 40 km/h (25 mph). For safety reasons, agencies in Europe generally identify a maximum speed limit for those streets and roads where the YTB law applies. In British Columbia, for example, the law is in effect only where speeds are less than 60 km/h (37 mph).

Active stakeholder involvement is essential early in the legislative process. Education of both motorists and transit employees is necessary. In practice, YTB laws are difficult to enforce consistently and extensively, and function more as a "good driving practice" reminder than as a truly effective transit priority measure. The law cannot be assumed to eliminate the bus re-entry problem.

Table 5-1. Approximate Number of Berths Required—Five Percent Failure (*38*)

Dwell Time at Stop (seconds)	10 sec	20 sec	30 sec	40 sec	50 sec	60 sec
Buses per Hour						
Unsignalized						
15	1	1	1	1	1	1
30	1	1	1	1	1	2
45	1	1	1	1	2	2
50	1	1	2	2	2	3
75	1	2	2	2	3	3
90	1	2	2	2	3	4
105	1	2	3	3	4	4
120	2	2	3	3	4	5
Signalized (Green/cycle = 50 Percent)						
15	1	1	1	1	1	1
30	1	1	1	1	2	2
45	1	1	2	2	3	3
60	1	2	2	2	3	4
75	1	2	3	3	4	5
90	2	3	3	4	5	5
165	2	3	4	5	5	6
180	2	3	4	5	6	7

5.2.2 Street-Side Bus Stop Design

Curbside Bus Stops

Curbside stops (or in-lane stops) are the most frequently found street-side bus stop treatments in North America. They require no special roadway infrastructure modifications and allow for flexibility in the placement or relocation of stops. When the curb lane is used by moving traffic, the stops eliminate bus merging and diverging movements. However, stopped buses may temporarily block other vehicles. Curbside stops are preferred by bus operators, but sometimes are of concern to traffic engineers for their impacts on other traffic. Transit service is sometimes provided on flush shoulder roadways, These stops may need to have low level platforms or landing pads installed to provide accesiblity.

Location

Bus stops should be placed consistently along any given street wherever possible. Bus stops should be located to accommodate the need for a bus to change lanes in advance of an intersection and before approaches to a left turn. Whenever possible, bus stops should be beyond driveways to minimize the conflicts between buses and vehicles leaving or entering the driveway. Stops are desirable where:

- Nearby intersections are signalized;
- Curb length is adequate;

- No driveways or physical obstructions are within the bus stop zone;
- Access can be provided for passengers with disabilities;
- Large number of boarding and alighting passengers are served;
- Major trip generators are nearby;
- Pedestrian and cycling connections are convenient;
- Intersecting transit lines exist;
- Street lighting is available; and
- Space is available for amenities.

Curbside bus stops may be far-side, near-side, or mid-block depending upon factors such as:

- The number of lanes available to moving traffic;
- The presence or absence of curb parking;
- Traffic volumes and speed;
- Intersection turning movements;
- Traffic signal timing;
- Street capacities; and
- Potential for traffic preferential measures.

Far-side stops are desirable where traffic flows are heavy, buses have exclusive use of the lane, peak hour (or all day) parking is prohibited, and buses get priority at traffic signals. They are also desirable where there are slight distance and capacity problems, and where buses turn left.

Near-side stops sometimes are used where traffic conditions are not critical and curb parking is permitted even during peak periods. Buses are able to use the intersection area to re-enter the adjacent traffic lane. Near-side stops may be preferred for buses making right turns, but vehicles turning right and buses leaving stops could conflict with each other.

Mid-block stops generally are used in downtown areas, where many bus riders use the same boarding and alighting areas. They are used at major passenger generators or where space at an adjacent intersection is insufficient. However, they may increase walking distances for passengers coming from intersecting streets. Pedestrian crossings to reach a stop must be carefully considered.

Table 5-2 shows the general advantages and disadvantages of far-side, near-side, and mid-block stops.

Bus Stop Design Dimensions

Bus stops should be long enough to permit safe entry of buses without backing up into adjacent travel lanes or into the intersection. Figure 5-6 presents suggested guidelines for far-side, near-side, and mid-block stops. A zone accommodating a typical bus typically is 27 m (90 ft) long for far-side bus stops,

Table 5-2. Comparative Analysis of Bus Stop Locations (*35*)

Advantages	Disadvantages
Far-Side Stop	
• Minimizes conflicts between right turning vehicles and buses • Provides additional right-turn capacity by making curb lane available for traffic at intersections • Minimizes sight-distance problems on approaches to intersection • Encourages pedestrians to cross behind the bus • Creates longer deceleration distances for buses since the bus can use the intersection to decelerate • Results in bus drivers being able to take advantage of the gaps in traffic flow that are created at signalized intersections • Sight distance is improved for pedestrians • At intersections where heavy traffic flows diverge causing traffic volumes to be lighter on the leaving side than on the approaching side, far-side stops will minimize interference with major flows • Waiting passengers accumulate at less crowded sections of sidewalks rather than close to the intersection • Passengers are encouraged to leave by the rear door, since it is closer to the street corner, and as a result, loading and unloading time is reduced • Conducive to bus signal priorities at signalized intersections	• Could result in traffic queued into intersection when a bus is stopped in travel lane or more buses than fit at the stop arrive at the same time • May obscure sight distance for crossing vehicles • If signal priority not in use, can cause a bus to stop far side after stopping for a red light, which interferes with both bus operations and other traffic • May increase number of rear-end accidents since drivers do not expect buses to stop again after stopping at a red light and proceeding across an intersection
Near-Side Stop	
• Minimizes interference when traffic is heavy on the far side of the intersection • Allows passengers to access buses closest to crosswalk • Results in the width of the intersection being available for the driver to pull away from curb • Eliminates the potential of double stopping • Allows passengers to board and alight while the bus is stopped at a red light • Provides driver with the opportunity to look for oncoming and crossing traffic, including other buses with potential passengers (to improve transfers) • Eliminates double-stopping at stop sign controlled intersection	• Increases conflicts with right-turning vehicles • Buses moving around stopped vehicles may conflict with moving traffic in adjacent lane • Precludes traffic signal priorities • May result in stopped buses obscuring curbside traffic control devices and crossing pedestrians • May cause sight distance to be obscured for cross vehicles stopped to the right of the bus • Increases sight distance problems for crossing pedestrians • Reduces capacity of bus stop if bus is ready to go but stopped by a red signal. • Reduces capacity of intersection when bus is stopped during available green time
Mid-Block Stop	
• Minimizes sight distance problems for vehicles and pedestrians • May result in passenger waiting areas experiencing less pedestrian congestion	• Requires additional distance for no-parking restrictions • Encourages passengers to cross street mid-block (jaywalking) • Increases walking distance for passengers crossing at intersections

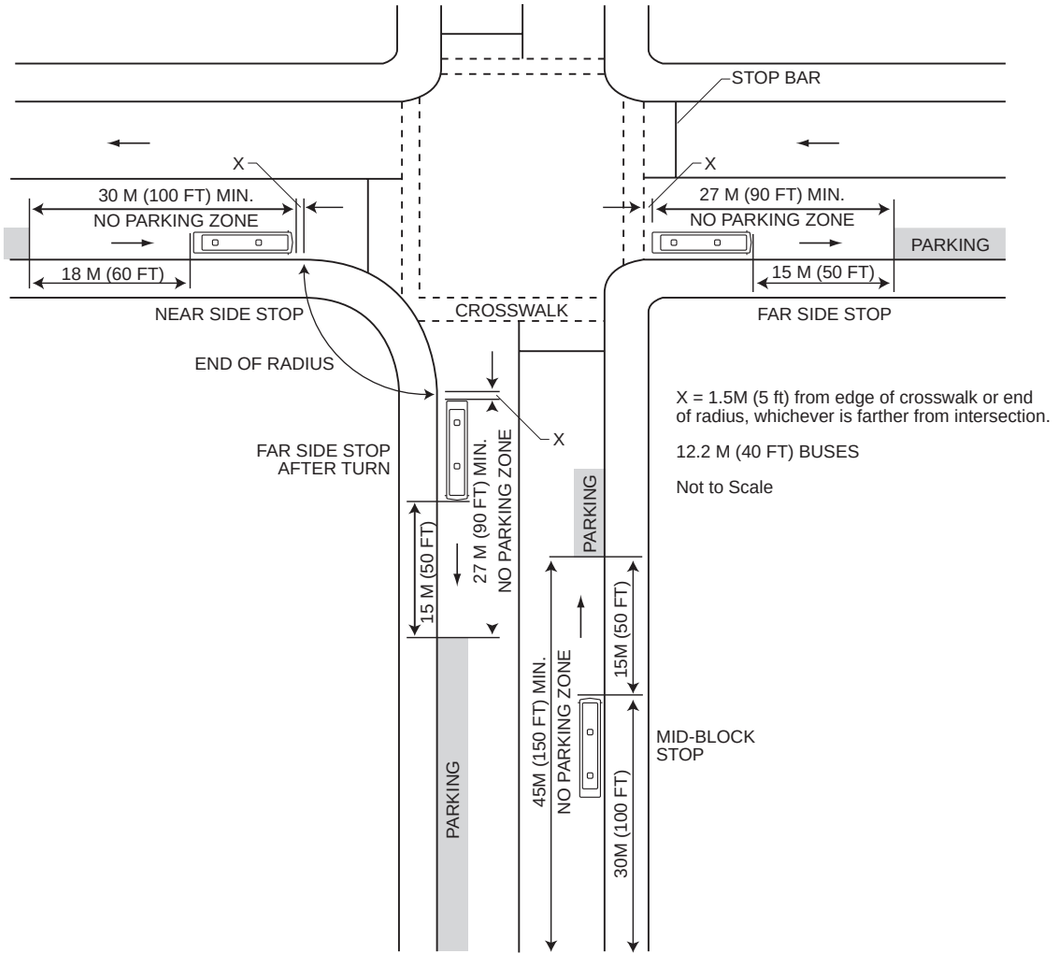


Figure 5-6. Typical Bus Stop Zone Dimensions (*35*)

30 m (100 ft) for near-side bus stops, and 45 m (150 ft) for mid-block bus stops. If articulated buses are to be used, the bus stop zone should be extended 6.1 m (20 ft). The bus zone length should be increased if more than one bus is expected to use the stop at one time. The extension should be 15.2 m (50 ft) for each additional standard 12.2-m (40-ft) bus and 21.3 m (70 ft) for each additional 18.2-m (60-ft) articulated bus.

Near-side bus stops should be set back at least 1.5 m (5 ft) from a pedestrian crosswalk. On streets in business districts where curb parking is permitted, bus zones should be clearly marked to keep the area free of parked or stopped cars at all times.

Bus Bulbs and Curb Extensions

A bus bulb (or bus nub or curb extension) involves the extension of a sidewalk across a shoulder or parking lane to the edge of the first through traffic lane. Bus bulbs may be located on the near-side, far-side, or both sides of an intersection. Buses stop in the moving traffic lane to pick up and discharge passengers. Figures 5-7 and 5-8, respectively, show examples of a "bus bulb" at a far-side and a mid-block bus stop.

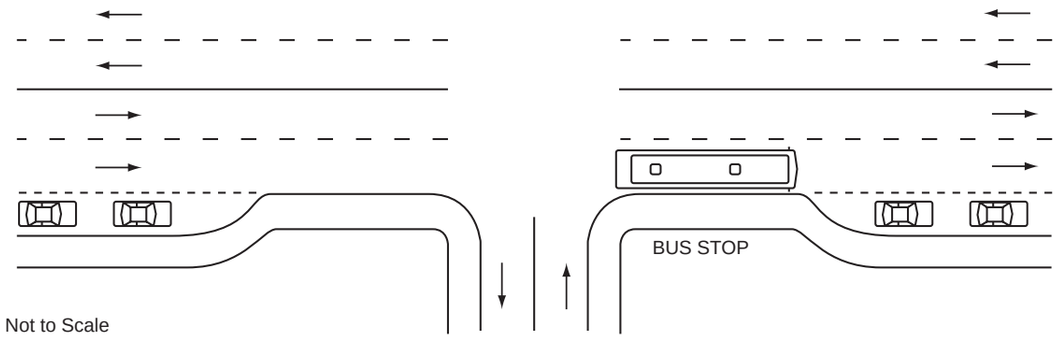
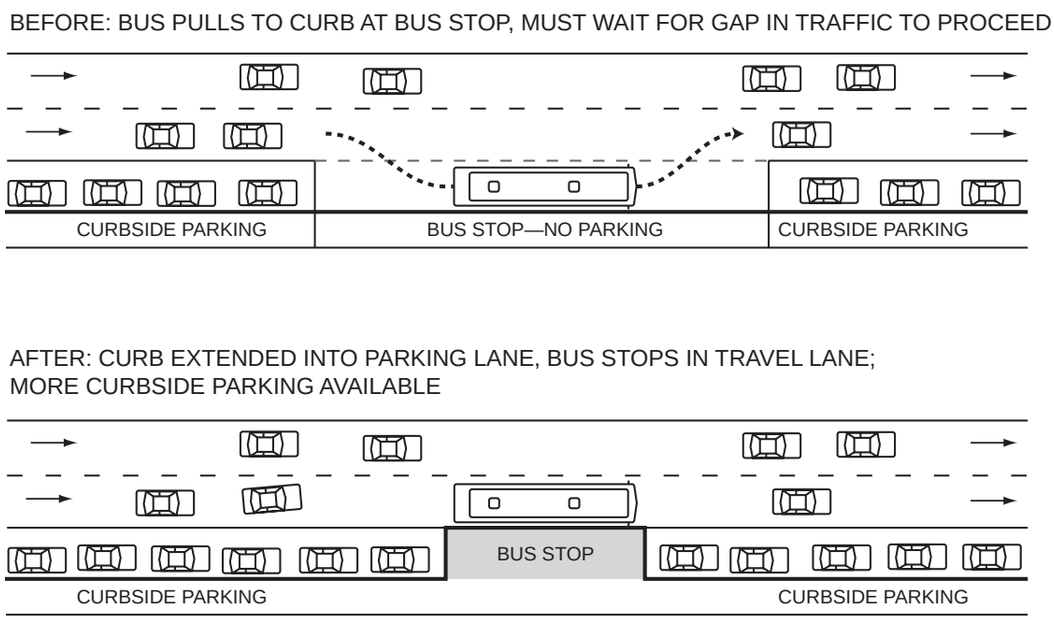


Figure 5-7. Far-Side Bus Bulb (*35*)

Bus bulbs and curb extensions provide additional space for waiting, boarding, and alighting passengers. They better segregate waiting bus passengers from pedestrians walking along sidewalks, reduce street crossing distances for pedestrians, and provide space for amenities such as shelters and bus benches. They eliminate lateral movement of buses to enter and leave stops, and they eliminate possible delays for buses re-entering a moving traffic lane. They also can result in more on-street parking than would exist with a conventional bus stop that requires additional space for bus transitions.

Bus bulbs and curb extensions may cause cars to queue behind a stopped bus and encourage motorists to make unsafe maneuvers when changing lanes to avoid a stopped bus. They also preclude adding road capacity through the elimination of curb parking, and they cost more than conventional bus stops because of changes in street drainage.



Source: TCRP Report 100, Exhibit 4-30, pg. 4-30.

Figure 5-8. Mid-Block Bus Bulb Created by Curb Extension (*38*)

Application

Bus bulbs and curb extensions are recommended for streets that are perceived to be pedestrian friendly, have relatively low traffic volumes, and allow curb parking. They may be appropriate in urban settings with high-density, mixed-use developments and crowded sidewalks—where the number of people moving along the street as pedestrians or as transit patrons is high and may exceed the number of people in personal vehicles (*29*).

Specific conditions that support the construction of bus bulbs or curb extensions include:

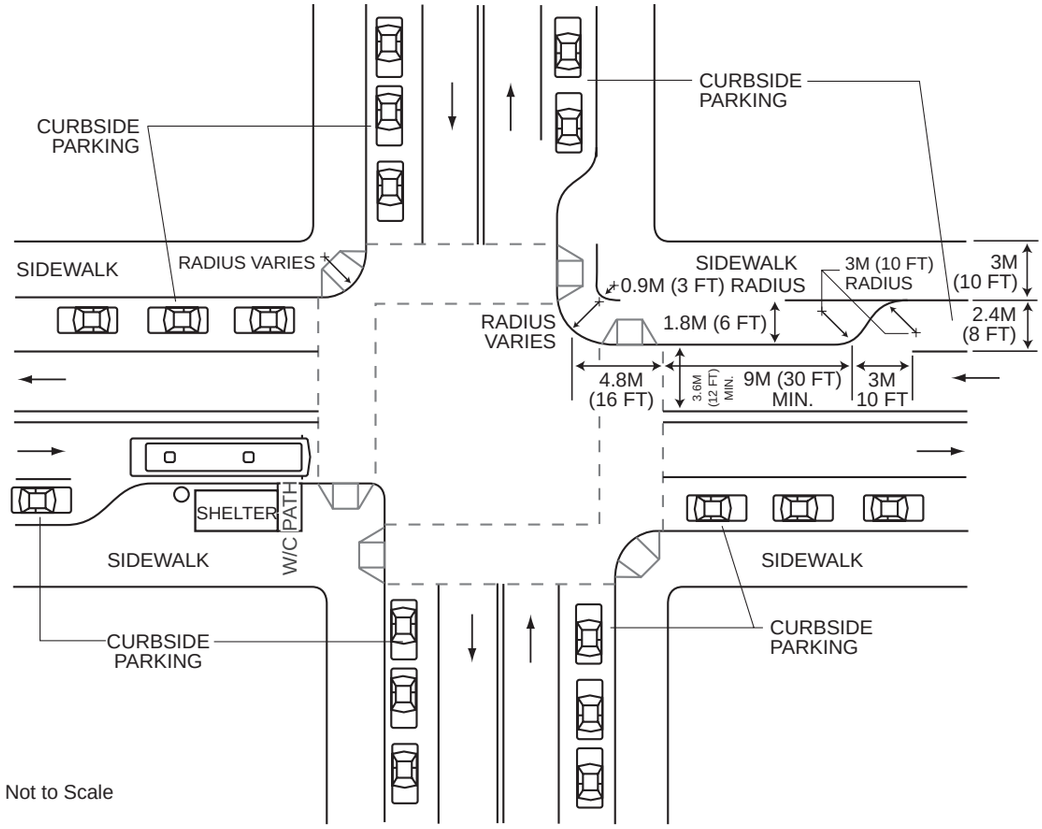
- Frequent transit service;
- High levels of transit ridership in the corridor or at the bus stop;
- High levels of pedestrian activity on sidewalks;
- Low roadway operating speeds;
- Presence of 24-hour, on-street parking (either diagonal or parallel);
- Two travel lanes in each direction to allow passing of stopped buses;
- Conditions where bus drivers find difficulty in re-entering the stream of traffic;
- Locations with bus lanes along left side (interior); and
- Areas where traffic calming is desirable.

Bus bulbs and curb extensions are *not recommended* where traffic uses the curb lanes along high-speed or high-volume arterials, where buses make right turns, or where vehicles stopped behind a bus may affect other traffic. The site characteristics that do not support the use of bus bulbs include:

- Corridors with low transit ridership;
- Corridors with low pedestrian activity;
- Streets with high traffic volumes;
- Streets where 24-hour, on-street parking is not available;
- Streets with high bicycle traffic;
- Streets with only two-lanes (where traffic cannot pass a stopped bus);
- Sites with drainage problems (making boarding difficult for patrons); and
- Bus stops where buses layover.

Design Dimensions

A bus bulb is constructed by extending the curb into the parking lane to create additional space for pedestrians to walk and transit patrons to wait for the bus. The extended area can provide space for transit amenities, street furniture, or landscaping. The bulb should be a minimum of 1.8 m (6 ft) wide leaving a 0.6-m (2-ft) offset between the bulb and the edge of the travel lane. It should be long enough to allow for the simultaneous boarding of several buses as required.



Source: TCRP Project D-09, Task 7-4 Bus Pull-Outs, p. 16.

Figure 5-9. Bus Bulb with Near-Side Stops (*38*)

Provisions for cyclists should be considered, since bicycle lanes may have to be routed around the curb extension, creating potential pedestrian/bicycle or vehicle/bicycle conflicts. Drainage patterns may need to be reworked to prevent water from ponding near the stop. Right-turn restrictions may be required because of the tighter curb radius associated with the treatment.

The near-side bus bulb design (Figure 5-9) limits opportunities for bus traffic signal priorities. Cars behind a stopped bus, however, are queued mid-block. The far-side bus bulb design (Figure 5-10) permits bus traffic signal priority, and cars turning right can use the curb lane. However, cars behind stopped buses could back up across the intersecting street unless they change lanes.

Bus Bays

Bus bays (pull-outs, turnouts, laybys) are used mainly on high-speed suburban roads. A bus bay allows buses to stop without impeding traffic flow by pulling into a bus stop zone out of the main travel lanes, benefiting general traffic flow because buses are removed from the traffic stream when loading and unloading passengers. From a transit perspective, bus bays improve safety for passenger alighting and boarding and provide a protected area away from moving traffic for stopped buses with long dwell times or for layover.

Traffic engineers favor the use of bays since stopped buses do not delay other vehicles. Transit operators generally oppose bays because of the difficulty buses have re-entering the traffic stream. When traffic

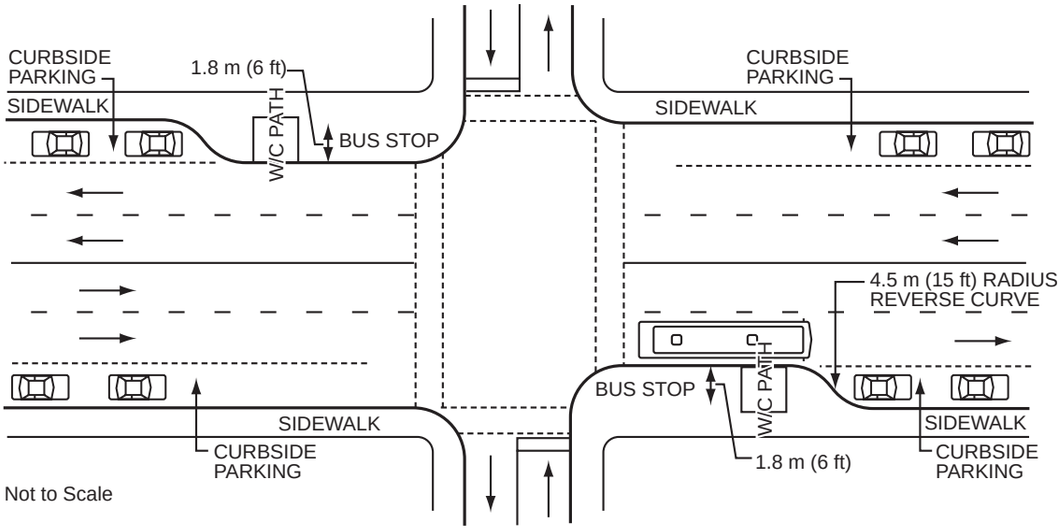


Figure 5-10. Bus Bulb with Far-Side Stops (*38*)

exceeds 1,000 vehicles per hour per lane, re-entering the traffic stream becomes extremely difficult, and buses may be delayed while waiting to re-enter. Reducing sidewalk space can have a negative impact on the passenger waiting area and on the flow of pedestrian activity.

Bus bays are often constructed by reducing the sidewalk or merge area adjacent to the street or by displacing existing curb parking. Such modifications usually require capital expenditures and may be warranted only on arterial roads with high-volume or high-speed traffic, especially at bus stops with a large number of passenger boardings with long transit dwell times.

Application

Bus bays generally are provided where space is available, travel speeds are high, traffic volumes are heavy, and safety is a concern. Consequently, they are more common in suburban settings than within urban settings. Bus bays should be considered when the following conditions apply:

General

- Right-of-way width is adequate to construct the bay without adversely affecting sidewalk pedestrian movement; and
- Improvements such as widening are planned for a roadway, presenting an economic opportunity to include a pull-out in the construction process.

Traffic

- The curb lane is (or will be) used by moving traffic;
- Traffic in the curb lane is between 250 and 500 vehicles during the peak hour;
- Traffic speed is greater than 64.4 km/h (40 mph);
- Potential exists for vehicle/bus conflicts that warrant separation of transit and passenger vehicles;

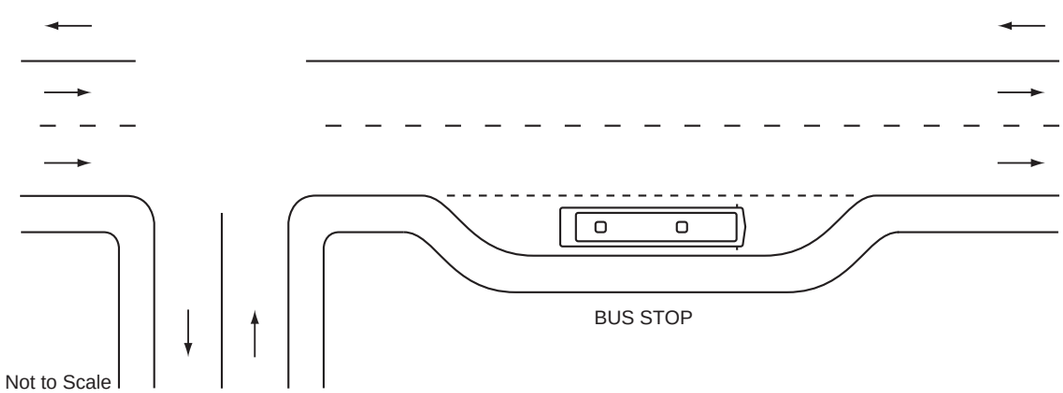
- There is a history of repeated traffic and/or pedestrian accidents at the stop location (particularly rear-end collisions with stopped buses);
- Sight distances (hills, curves) prevent traffic from stopping safely behind a stopped bus;
- A right-turn lane is used by buses as a queue jump lane;
- Appropriate bus signal priority treatment exists at the intersection (near-side stop);
- Bus volume is between 10 to 15 each way in the peak hour on the roadway;
- Passenger volume exceeds 20 to 40 boardings per hour each way;
- Average peak-period dwell time exceeds 10 to 30 seconds per bus, or the bus stop location is a layover at the end of the bus trip;
- Bus parking in the curb lane is prohibited or can be prohibited; and
- The bus has extended layover times to accommodate transferring passengers.

Types

Bus bays can be closed or open-ended, and near-side, far-side, or mid-block. They also may incorporate queue bypass lanes. The following sections describe each type.

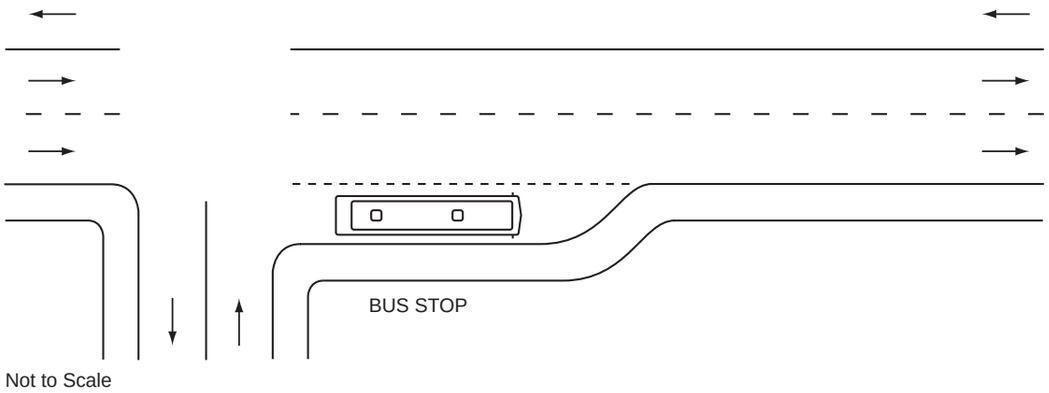
Closed Bus Bays. Figure 5-11 depicts a typical closed (standard) bus bay. Closed bus bays usually are located as far-side bus stops at signalized intersections. The signal creates breaks in the flow of traffic to permit bus drivers to re-enter the travel lane. They also are provided at mid-block bus stops near major transit destinations with high passenger activity and longer-than-average dwell time. Near-side bus bays are generally not recommended because of conflicts with vehicles approaching the intersection in curb lane to make a right turn. Bus service may be delayed while the bus driver tries to maneuver out of the bus bay into the travel lane to proceed through the intersection.

Open Bus Bay. Figure 5-12 illustrates an open bus bay, a variation on the closed bus bay. It is located at the beginning of a block and is open to upstream traffic. The bus driver can decelerate across the intersection and then move from the travel lane into the bay. This allows the bus to move efficiently into the bus



Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p. 6.

Figure 5-11. Closed Bus Bay (*38*)



Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p. 7.

Figure 5-12. Open Bus Bay (*35*)

bay and to stop out of the flow of traffic. Major disadvantages are that (1) bus re-entry into the general traffic lane may be delayed by through traffic, and (2) passenger loading areas and pedestrian walking space may be compromised. Pedestrian walking distance to cross the intersection is increased because the intersection width is increased by the width of the bus bay. The open bus bay can create conflicts for right-turning vehicles from the cross street that use the bus bay for acceleration (see the following discussion of a partial open bus bay).

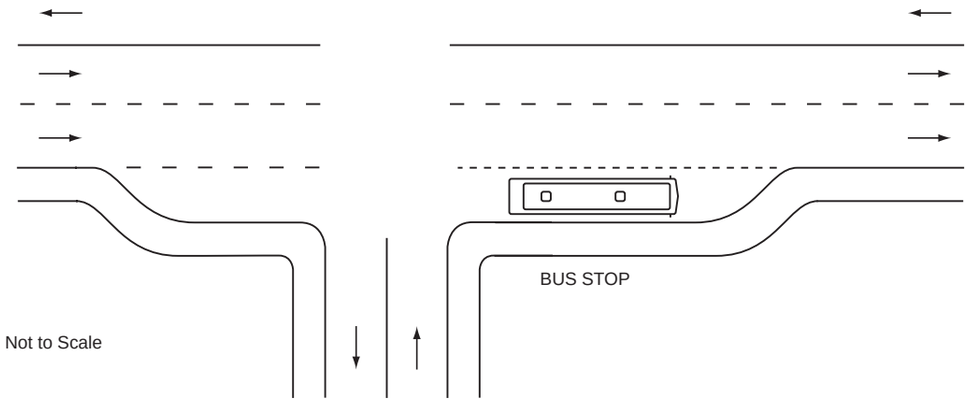
As with a closed bus bay, an open bus bay is located on the far side of a signalized intersection. The signal creates breaks in the flow of traffic to permit bus drivers to re-enter the travel lane. A near-side open bus bay at an intersection may result in use by right-turning traffic, but it may be feasible as part of a queue jump bus bay (see the following discussion).

Partially Open Bus Bay. A variation on the standard bus bay is a partially open bus bay, also known as a partial sidewalk extension. This design extends the sidewalk area slightly (approximately 1.8 m [6 ft]) into the intersection at the open end of a far-side bus bay. The extension prevents right-turning vehicles from using the bus bay as an acceleration lane. It still allows buses to use the intersection approach to enter the bay and provides a sidewalk extension to reduce the pedestrian crossing distance.

Queue Jump Bus Bay. A queue jump bus bay allows buses to bypass traffic queued at a signalized intersection. An open bus bay is located at the end of the block on the far side, along with an open lane on the near side. Figure 5-13 illustrates a queue jump bus bay. The bay is most effective with signal prioritization that allows buses to bypass traffic congestion by moving ahead of other vehicles through the intersection. The bays are also used in combination with a right-turn-only lane from which buses are expected. Giving priority to bus movements at the intersection can speed up both bus and overall traffic flow.

A queue jump bus bay requires an open bus bay on the far side of the intersection where the bus stop is located, and an extended lane on the near side of the intersection to bypass the traffic queue stopped at the signal. The length of the extended lane should be sufficient to exceed the traffic queue but not less than 73 m (240 ft). The extended bus lane can be designed as a right-turn-only lane (except buses).

Off-Street, Half-Sawtooth Bus Bay. Half-sawtooth bus bays sometimes are used where space is limited to provide the optimum number of bus loading positions. The configuration allows buses to leave the bus bay without having to wait for buses ahead of them to exit. They generally require greater station width



Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p. 8.

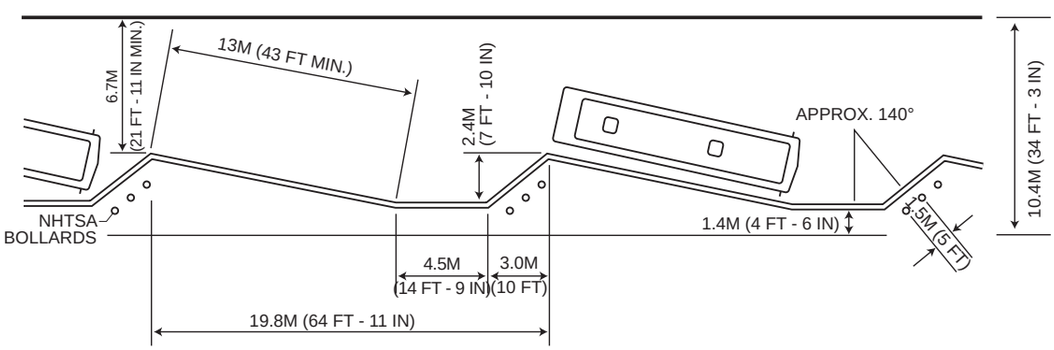
Figure 5-13. Queue Jump Bus Bay (*35*)

but permit shorter stations. The loading lane width shown in Figure 5-14 is the minimum berth length required for 12.2 m (40 ft) buses with bike racks. These lengths would have to be extended for articulated buses (*33*). Note that 10.4 m (34.25 ft) of width are needed for the bay compared with 3.6 m (12 ft) for a regular bay.

Bus Bay Design Dimensions

Bus bay designs typically incorporate five elements: an entrance taper, a deceleration area, the stopping area, an acceleration area, and an exit taper (*1*). Figure 5-15 illustrates these dimensions for each element of a bus bay. Table 5-3 provides sample lengths for acceleration lanes, deceleration lane, and entrance and exit tapers. The lengths are based on the through-speed of the adjacent travel lane and the speed of the bus entering the bus bay.

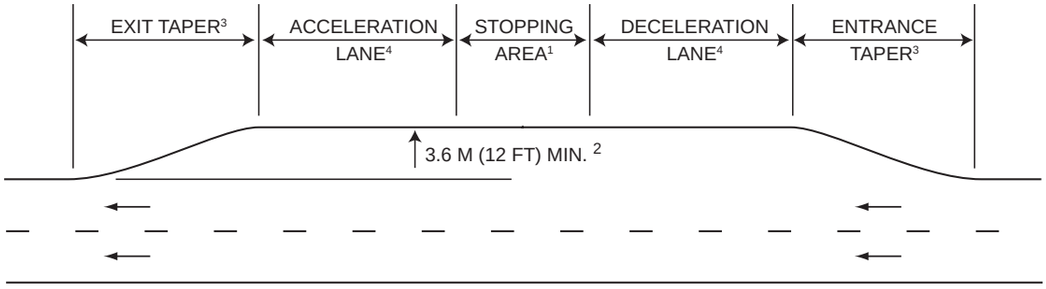
In the design of an open bus bay or a partially open bus bay, the distance available for deceleration includes the width of the upstream cross street. The bus driver can use the width of the intersection to decelerate and to move from the travel lane into the open bus bay. The entrance taper is not required for an open



Not to Scale

Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p. 47.

Figure 5-14. Half Sawtooth Bus Bay (*19*)



Not to Scale

(1) The bus stopping area should be 15 m (50 ft) for each standard 12.2 m (40 ft) bus and 21 m (70 ft) for each 18.3 m (60 ft) articulated bus expected to be at the stop at the same time.

(2) The width of the bus bay should be at least 3.6 m (12 ft), excluding gutter width. A bus bay 3 m (10 ft) in width may be acceptable with traffic speeds less than 50 km/h (30 m.p.h.)

(3) Taper lengths are a function of the street through speed and the width of the bus bay. Recommended taper lengths are listed in Table 5-3. A taper of 5:1 is the recommended minimum for an entrance taper from an arterial street into a bus bay. The recommended taper for re-entry into the traffic stream is not sharper than 3:1.

(4) Recommended acceleration and deceleration lane lengths are listed in Table 5-3.

Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p. 12.

Figure 5-15. Typical Bus Bay Dimensions (*35*)

Table 5-3. Sample Bus Bay Dimensions (*34*)

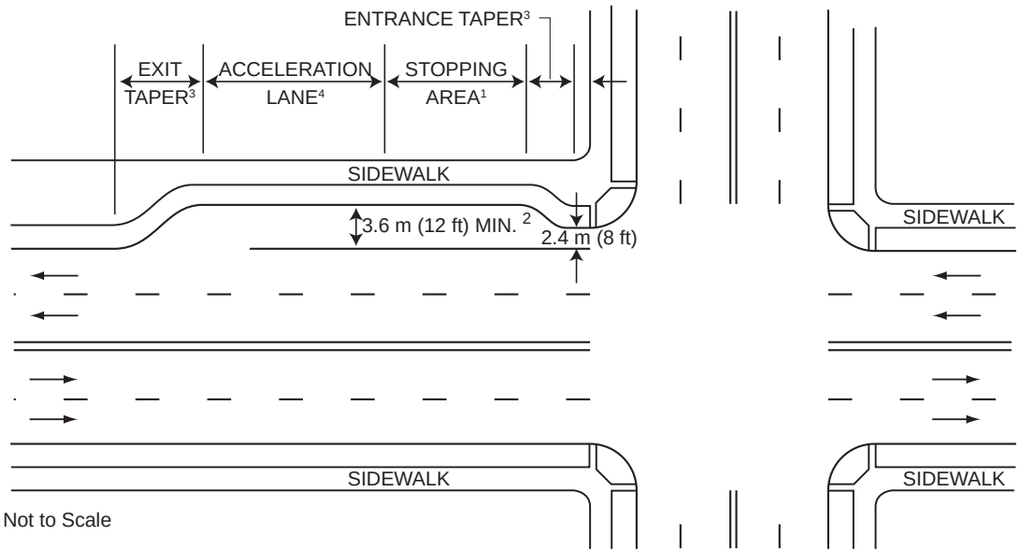
			Length					
	Thru Speed	Enter Speed	Entrance Taper	Decel. Lane	Stopping Area	Accel. Lane	Exit Taper	Total
Metric	km/h	km/h	m	m	m	m	m	m
	<50	<30	5:1 min	None	15	None	3:1 max	40
	60	40	50	55	15	75	50	245
	70	50	65	110	15	215	65	470
	80	60	70	145	15	295	70	595
	90	70	75	180	15	425	75	770
	100	80	80	225	15	580	80	980
U.S.	mph	mph	ft	ft	ft	ft	ft	ft
	<30	<20	5:1 min	None	50	None	3:1 max	130 min
	35	25	170	185	50	250	170	825
	40	30	190	265	50	400	190	1,095
	45	35	210	360	50	700	210	1,530
	50	40	230	470	50	975	230	1,955
	55	45	250	595	50	1,400	250	2,545
	60	50	270	735	50	1,900	270	3,225

Notes: 1. Entering speed to be within 15 km/h (10 mph) of through-speed at end of taper.

2. Tapers based on standard 3.65-m (12-ft) bus bay width. 3.0 m (10 ft) minimum is acceptable for traffic speed under 50 km/h (30 mph)

3. Add 6.1 m (20 ft) to length of stopping area if it is to be used by 18.1 m (60 ft) long articulated buses.

4. Deceleration rate 4 km/h/sec (2.5 mph/sec).



(1) The bus stopping area should be 15 m (50 ft) for each standard 12.2 m (40 ft) bus and 21 m (70 ft) for each 18.3 m (60 ft) articulated bus expected to be at the stop at the same time.

(2) The width of the bus bay should be at least 3.6 m (12 ft), excluding gutter width. A bus bay 3 m (10 ft) in width may be acceptable with traffic speeds less than 50 km/h (30 m.p.h.)

(3) Taper lengths are a function of the street through speed and the width of the bus bay. Recommended taper lengths are listed in Table 5-3. A taper of 5:1 is the recommended minimum for an entrance taper from an arterial street into a bus bay. The recommended taper for re-entry into the traffic stream is not sharper than 3:1.

(4) Recommended acceleration and deceleration lane lengths are listed in Table 5-3.

Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p.12.

Figure 5-16. Partially Open Bus Bay Dimensions (*35*)

bus bay. The entrance taper is required for the partially open bus bay, but the distance can be adjusted to reflect the width of the partial sidewalk extension. Figure 5-16 illustrates the suggested dimensions for a partial open bus bay.

Summary Comparison

Table 5-4 lists the advantages and disadvantages of the various bus stop treatments.

5.2.3 Curbside Bus Stop Design

On-street bus stops typically share sidewalk space with other activities. When examining the area required for a bus stop, adequate space should be provided for people who are waiting for a bus and for those passing by. Depending on passenger volumes, there may also be the need for other facilities such as a shelter, benches, and amenities. Site design of bus stops includes establishing the platform (pad) height, length and width, developing bus shelters, designs, and providing amenities within the stop or station area.

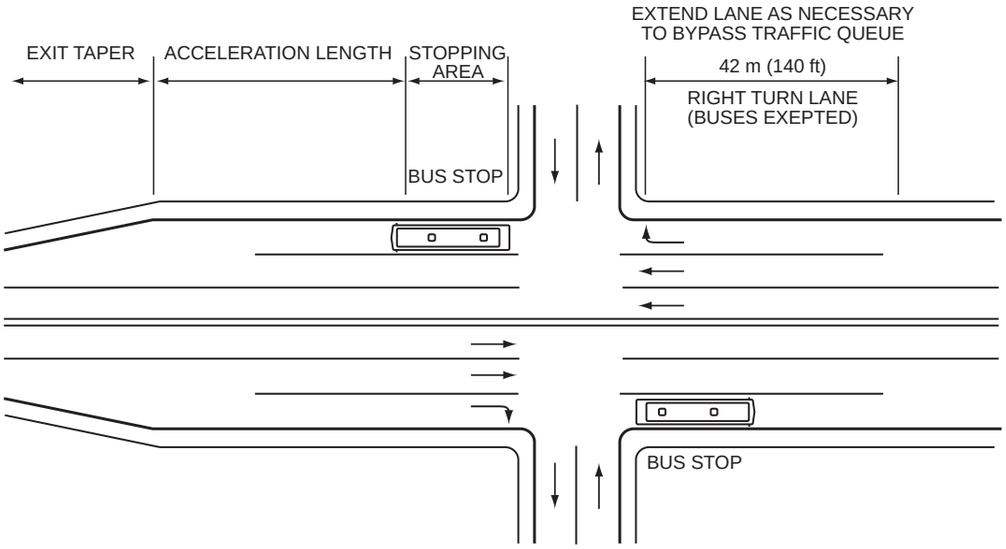


Figure 5-17. Typical Queue Jump Bus Bay

Table 5-4. Advantages and Disadvantages of Various Bus Stop Treatments (*35*)

Advantages	Disadvantages
Curbside Bus Stop	
For Transit Operations • Provides easy access for bus drivers • Eliminates merging maneuvers • Requires minimal infrastructure modifications; easy to relocate *For Traffic Management* • Appropriate for low volume roadways with less frequent bus service *For Pedestrians* • Increases the chances of locating bus stops more frequently or more conveniently	*For Transit Operations* • Increases risks for bus passengers boarding and alighting *For Traffic Management* • Impacts other traffic, other vehicles that may queue behind bus • Other drivers may make unsafe lane changes to avoid stopping behind a bus *For Pedestrians* • May require passengers to walk between parked cars or to get to the curb lane • Increases the risk of a vehicle/pedestrian conflict
Bus Bay	
For Transit Operations • Provides a protected area away from moving traffic for bus stopped for a long dwell time or layover • Allows buses to drop off and pick up passengers outside travel lanes *For Traffic Management* • Bus stops out of moving traffic lane • Minimizes traffic delays due to bus operations *For Pedestrians* • Improves safety for passenger boarding and alighting by increasing the distance between passengers and moving traffic	*For Transit Operations* • May present problems to bus drivers trying to re-enter traffic, especially in high-speed or high-volume traffic • Requires infrastructure modifications; more difficult to relocate *For Traffic Management* • Creates bus/vehicle conflicts when buses re-enter a busy travel lane • May reduce parking space curbside *For Pedestrians* • May reduce sidewalk space and increase pedestrian congestion

Table 5-4. Advantages and Disadvantages of Various Bus Stop Treatments (*35*) (*continued*)

Advantages	Disadvantages
Open Bus Bay (in addition to the advantages/disadvantages for Bus Bays)	
For Transit Operations • Allows buses to decelerate through the intersection and move into bus bays more efficiently	*For Traffic Management* • Can create a conflict for right-turning vehicles using open bus bay for acceleration movements *For Pedestrians* • Increases pedestrian crossing distance at an intersection by width of bus bay
Partial Open Bus Bay (in addition to the advantages/disadvantages for Bus Bays and Open Bus Bays)	
For Traffic Management • Prevents right-turning vehicles from using the open bus bay for acceleration movements *For Pedestrians* • Reduces pedestrian distance for crosswalk	
Queue Jump Bus Bay (in addition to the advantages/disadvantages for Bus Bays)	
For Transit Operations • Allows buses to proceed through intersection in advance of other traffic *For Traffic Management* • Gives priority to bus movements at the intersection can speed up overall traffic flow	*For Traffic Management* • May cause delays to right-turning vehicles if the queue Jump bus bay is used in combination with a right-turn-only lane for general traffic
Bus Bulb	
For Transit Operations • Improves safety for passengers while alighting and boarding • Provides easy access for driver to bus stop • Eliminates delay for bus returning to travel stream *For Traffic Management* • Improves speed for transit as compared to bus bay or pull-out • Used in combination with parking in the curb lane • Removes fewer parking spaces for the bus stop than curbside stop or bus pull-out *For Pedestrians* • Provides additional sidewalk area for pedestrians and bus patrons to wait for bus • Reduces pedestrian distance to cross street	*For Transit Operations* • Bus is not removed from travel lane while passengers alight and board • Requires a larger capital investment than curbside bus stop; more difficult to relocate *For Traffic Management* • Impacts other traffic, other vehicles that may queue behind bus • Other drivers may make unsafe lane changes to avoid stopping behind a bus *For Pedestrians* • None. Bus bulbs primarily benefit bus patrons and pedestrians.

Design Factors

Key factors that will govern the dimensions and design of bus platforms (pads) and related stop feature include the following:

- The available widths between the street curb and the building (or sidewalk);
- The presence or absence of sidewalks;
- The number and types of buses that will use the stop at any given time;

- Passenger boardings, alightings, and accumulations in the stop area during peak period; and
- Fare collection policies.

The designs should provide:

- Adequate space for waiting passengers to avoid overcrowding;
- Hard (paved) surface for the platform (or pads);
- Passenger shelters, especially at heavily used stops or stations;
- Passenger amenities such as benches, telephones, and bus route and schedule information;
- Adequate illumination and security provisions;
- ADA requirements; and
- A consistent design theme (important for bus rapid transit operation).

Bus Platform Design

Platform design should meet ADA requirements. Loading areas should allow for wheelchair lift usage, include provisions at shelters, and provide connections to pedestrian pathways. A 2.4-m (8-ft) depth and a 1.5-m (5-ft) width are required for wheelchair mobility (*24*). The area should be free of obstructions.

Bus Platforms (Pads)

Bus platforms (pads) should be at least 2.4 m (8 ft) wide. If there are no adjacent sidewalks, a 3-m (10-ft) width should be provided. Where curb-to-building distance is less than 3 m (10 ft), reduced pad widths [e.g., 1.5 m (5 ft)] may be necessary.

The bus platform should be long enough to cover all doors of buses that stop at any given time, or a minimum of 7.5 m (25 ft). Specific dimensions will depend on the size, shape, and orientation of passenger shelters, and on the number of waiting passengers. The curb line and sidewalk should extend the full length of the platform to allow safe and efficient passenger boarding and alighting.

Passenger waiting areas should allow people to congregate without overcrowding. This is especially important at major bus stops that serve large traffic generators or multiple bus routes. Size requirements can be computed according to procedures set forth in the *Transit Capacity and Quality of Service Manual* (*38*).

Table 5-5 lists the pedestrian LOS for queuing areas. The required space for passenger service areas should be based on maintaining a desirable LOS. For most bus stops, the design LOS should be "C" to "D" or better. To determine the desired bus stop size, the following steps are recommended:

1. Based on the desired LOS, choose the average inter-person spacing from Table 5-5.
2. Estimate the maximum demand of passengers waiting for a bus at a given time.
3. Calculate the effective waiting area required by multiplying the average passenger space by the maximum passenger demand.
4. Calculate the total required waiting area by adding a 450-mm (18-in.) buffer width (next to the roadway) to the effective waiting area (*38*).

Table 5-5. Levels of Service for Queuing Areas (*38*)

LOS	Average Pedestrian Area		Average Inter-Person Spacing	
	(m^2/p)	(ft^2/p)	(m^2/p)	(ft^2/p)
A	>= 1.2	>= 13	>= 1.2	>= 4.0
B	0.9–1.2	10–13	1.1–1.2	3.5–4.0
C	0.7–0.9	7–10	0.9–1.1	3.0–3.5
D	0.3–0.7	3–7	0.6–0.9	2.0–3.0
E	0.2–0.3	2–3	<0.6	<2.0
F	<0.2	<2	Variable	Variable

Accessibility Features

An appropriate curb height for efficient passenger-service operation is between 150 mm (6 in.) and 225 m (9 in.). Buses will be prevented from moving close to higher curbs, and operation of a wheelchair lift could be compromised. Low-floor buses may have difficulty operating where high curbs are present. If there is no curb or the curb is too low, elderly persons, persons with mobility impairments, or passengers with child strollers may have difficulty boarding and alighting.

The urban design, lighting, visibility, grade, and accessibility of both the bus stop and approach pathways should be coordinated. All bus stops should be accessible by hard-surfaced sidewalks or pathways that are cleared and maintained in all seasons. Sidewalks at bus stops should be relatively level, in addition to being wide enough so that wheelchair lifts will properly deploy.

The bus stop/bay surface should be a durable, stable material able to resist the heavy bus stopping loads (12,000 kg/25,000 lb.) and avoid pavement failure or rutting and ponding (which can lead to buses splashing water on waiting customers). Reinforced concrete pavement pads are the most common design approach to this problem. If a curb and gutter (urban) drainage system is in place, it is desirable that the bus bay drain to a continuous gutter at the edge of the traveled lane, rather than to the curb. This avoids the potential for passengers being splashed by water or slush accumulating in the path of the bus wheel.

Shelters and Amenities

Various customer amenities may be included at bus stops. These include passenger shelters, benches, signing, special treatment of curbs and sidewalks, landscaping, telephones, passenger information, waste containers, and provisions for newspaper vending. Table 5-6 lists the advantages and disadvantages of various passenger amenities.

The primary function of shelters is to protect passengers from poor weather and to provide amenities such as seating, route maps, advertising panels, and lighting. Shelters should be provided at busy stops, transfer points, and at other locations to the extent that resources permit establishing the stop. Cost considerations may limit the number of bus stops that have shelters. Factors to consider when establishing warrants and priorities for shelters include:

- Number of passengers using the stop;
- Average passenger waiting time (simple to determine at ordinary pick-up stops, but may be more complex at transfer points);

Table 5-6. Advantages and Disadvantages of Passenger Amenities at Bus Stop

Amenity	Advantages	Disadvantages
Shelters	• Provide comfort for waiting passengers • Provide protection from climate-related elements (sun, glare, wind, rain, snow) • Help identify the stop	• Require maintenance, trash collection • May be defaced by graffiti
Benches	• Provide comfort for waiting passengers • Help identify the stop • Low cost when compared to installing a shelter • Provide opportunity to generate advertising revenue	• Require maintenance • May be defaced by graffiti
Vending Machines	• Provide reading material for waiting passengers	• Increase trash accumulation • May have poor visual appearance • Reduce circulation space • Can be vandalized
Lighting Provisions	• Increase visibility • Increase perceptions of comfort and security • Discourage "after hours" use of bus stop facilities by indigents	• Require maintenance • May be defaced by graffiti
Trash Receptacles	• Provide place to discard trash • Keep bus stop clean	• May be costly to maintain • May have a bad odor • May increase security risk
Telephones	• Are convenient for bus patrons • Provide access to transit information	• May encourage loitering at bus stop • May encourage illegal activities at bus stop
Route or Schedule Information	• Is useful for first-time riders • Helps identify bus stop • Can communicate general system information	• Must be maintained to provide current information • May be defaced by graffiti

- Degree of exposure to wind and weather;
- Availability of alternative nearby shelter;
- Adequacy of sidewalk or boulevard width to accommodate placement of the shelter at or close to the actual stop;
- Proximity of suitable street lighting or other illumination to ensure that both the outside and the inside of the shelter have adequate visibility to deter both crime and vandalism; and
- Absence of obstructions that limit visibility of the shelter (*34*).

Shelter design should be simple and functional. Shelters should be located and designed so that oncoming buses are clearly visible early enough for waiting passengers to react and move to the stopping door and/or flag the bus operator. Shelter placement should consider locations of lifts on buses.

The design of shelters should provide a consistent theme in terms of identity and image. This is especially important where BRT operation is planned. Passenger security can be achieved by designs that offer

defensible space, are open, and avoid blind corners. Emergency telephones should be provided at major stops or stations, and closed circuit television monitoring may be appropriate. Solar panels may power lighting and other shelter amenities. Landscaping around stops is desirable but it should not obstruct visibility or create a hiding place for criminals.

5.3 BUS OPERATION IN SHARED LANES (MIXED TRAFFIC)

For bus routes in mixed traffic, where the buses share lanes with general traffic, lane widths, intersection turning radii, and overhead clearances should be adequate for bus operations. Traffic engineering treatments that improve general traffic flow will also benefit buses. Bus travel times and reliability can be further improved by bus-oriented treatments including traffic signal priorities, queue bypasses, and exemption from turn restrictions. The guidelines that follow also apply along streets with bus priority lanes.

5.3.1 Roadway and Intersection Geometry

Roadway geometry along bus routes should provide adequate lane widths and overhead clearances (also see Chapter 3). The following are clearance requirements for the lane in which the bus travels:

- Traffic lanes used by buses should be able to accommodate buses that are typically 3.2 m (10.5 ft) wide (with mirrors). Desirable lane widths are 3.6 m (12 ft) wide, with at least 3.3 m (11 ft). Designers should use 3.0 m (10 ft) lanes only when the bus envelope (mirror-to-mirror) is less than 2.9 to 3.0 m (9.5 to 9.8 ft).
- Overhead obstructions should be at least 3.6 m (12 ft) above the street surface. At least 4.4 m (14.5 ft) of clearance is desirable.
- Obstructions (posts, signs, vegetation) should not be located within 0.6 m (2 ft) of the edge of the traveled lane to avoid being struck by a protruding bus mirror.

Generally, bicycles and buses can share streets with bike lanes, wide curb lanes or paved shoulders with little or no conflicts. Bus stops are usually located on the right, and so buses making stops block the path of bicycles. Bicycles can navigate around a stopped bus with little difficulty. Bicyclists will have to manuever around more buses as the frequency of bus service and bus stops increase. Bus bays help to provide a continuous route for a cyclist, even when passengers are being loaded/unloaded. Design speeds of streets with frequent bus service and bus stops generally are low and allow bicyclists flexibility in maneuvering around buses.

High-speed roadways without adequate bicycle facilities may not be wide enough to accommodate both bicycles and buses, as shared use of the lane can pose safety concerns to bicyclists, decrease the comfort of both bicyclists and bus operators in the lane, and reduce the operational efficiency of the lane. Buses operating in other than the curb lane do not experience (or generate) such conflicts.

Intersection Turning Radii

Adequate corner radii are essential at intersections where buses make or have the potential to make right turns. A properly designed curb radius produces:

- Less bus/vehicle conflict at heavily used intersections (since buses can move more quickly and smoothly through the turn);

- Higher bus operating speeds and reduced travel time;
- Improved bus passenger comfort;
- A safer pedestrian environment (buses can turn without jumping curbs); and
- Less encroachment on opposing cross-street travel lanes.

Large curb radii are generally preferable for efficient bus operations and passenger comfort, but then crossing distances for pedestrians increase, detracting from the pedestrian and urban environment by devoting more space to vehicles and increasing the perceived distance between block faces. Higher vehicle turning speeds and greater crossing distances increase the pedestrian exposure to on-street vehicles and can influence how pedestrians cross an intersection, all of which are safety concerns.

A balance should be achieved, therefore, between the operational efficiency of the bus and the safety and comfort of pedestrians who are often the transit customers. Signal timing and median treatment decisions should reflect the additional pedestrian crossing time that results from larger curb radii.

The corner curb radius should be designed based on the following:

- Design vehicle characteristics, including bus turning radius (noting that where semi-trailer trucks are present, a bus may not be the critical design vehicle);
- Width and number of lanes on the intersecting street;
- Operating speed and speed reductions
- Driver behavior;
- On-street parking;
- Allowable bus encroachment into traffic lanes (including the potential to set back the stop bar on the intersecting street to allow a turning bus to swing into the opposing lane to complete a turn);
- Angle of intersection; and
- Pedestrian crossing patterns

Design Vehicles

Curb radii depend on the design vehicles selected. Chapter 3 specifies the range of turning radii for AASHTO transit design vehicles. The appropriate design vehicles depend on the types of agencies involved, the bus service offered and the vehicles in the fleet. A 15-to-17-m (50-to-55-ft) radius should accommodate urban transit, intercity bus, and most urban truck requirements. The choice of vehicle should consider both the existing bus fleet, and future service and equipment needs. For example, premium or express services often use highway coaches that have a significantly larger turning radius than a standard city transit bus.

The choice of design vehicles involves some tradeoffs. Selecting a vehicle with a tight turning radius minimizes the curb radius and affects the expansion of infrastructure, but limits the types of vehicles that can comfortably operate at that intersection.

Figure 5-18. Luggage Bay Bicycle Rack (*28*)

Bicycle Racks

Bicycle racks are becoming increasingly common and for some transit agencies have become a basic requirement for new fleet acquisition. A bicycle rack typically extends about 0.9 m (3 ft) from the front of the bus, depending on where it is mounted, the number of bikes it accommodates, the model, and rack manufacturer. Bicycle racks can add to a vehicle's outer swept path and thus affect its turning characteristics. The installation of a bicycle rack also increases the front overhang of a vehicle, when deployed, and adds approximately 0.3 m (1 ft) to the outer swept path of the vehicle. Although a bike rack increases the outer swept path, the impact on the track of the rear wheel is minor and as a result does not change the curb radius recommendations, with or without encroachment.

Some transit agencies use a luggage bay bicycle rack that is interior to the bus. While the overall exterior dimensions of the bus do not change, the luggage bay bicycle racks require a sidewalk clear area that is approximately 1.4 m (4.5 ft) wide and 2.7 m (9.0 ft) deep to allow adequate deployment of the rack that is pulled out and pushed into the bus. Bus stop designers should consult with transit agencies that use these interior racks to determine actual space requirements at a bus stop.

Width and Number of Lanes on the Intersecting Street

The width and number of lanes on the intersecting street can substantially alter curb radius requirements, since they give the bus driver more area in which to maneuver without encroaching on other lanes. Bicycle lanes and on-street parking can also serve to reduce curb radii needs. For example, for a maneuver from a street with a bicycle lane alongside on-street parking (assuming parking is restricted near the intersection) to a similar street, curb radius is not usually an issue and most transit design vehicles can be accommodated. Restriction of on-street motor vehicle parking near intersections also provides added safety benefits of improved sight lines and space for curb extensions to reduce pedestrian crossing distances.

Operating Speed and Speed Reductions

Slower operating speeds permit tighter turn radii. With minimum turning radii, speeds are generally 5 to 15 km/h (3 to 9 mph) with little variation in that range. Turning radii become more pronounced at speeds over 25 km/h (15 mph).

Driver Behavior

Real-world variations in turning movements are influenced by driver behavior as well as vehicle turning characteristics. Turning templates and their application in providing guidance to the design professional should be considered in light of real-world operations. Designers often build in additional clearance, beyond the typical templates, to provide a margin of error and to accommodate variability in driver behavior.

Transit drivers must balance competing factors, including speed, passenger comfort, and driver comfort, in terms of their willingness to "turn" the wheel. On larger vehicles, drivers tend to overcompensate and attempt a wider turn, even if the turning characteristics of the vehicle are similar to those of a smaller vehicle (i.e., articulated bus turning characteristics are comparable to a standard city bus). In situations with tighter curb radii, drivers attempt to smooth the turn by encroaching on the lane opposing the receiving lane or by encroaching on the area adjacent to the departure lane. To illustrate this point, Figure 5-19 compares the

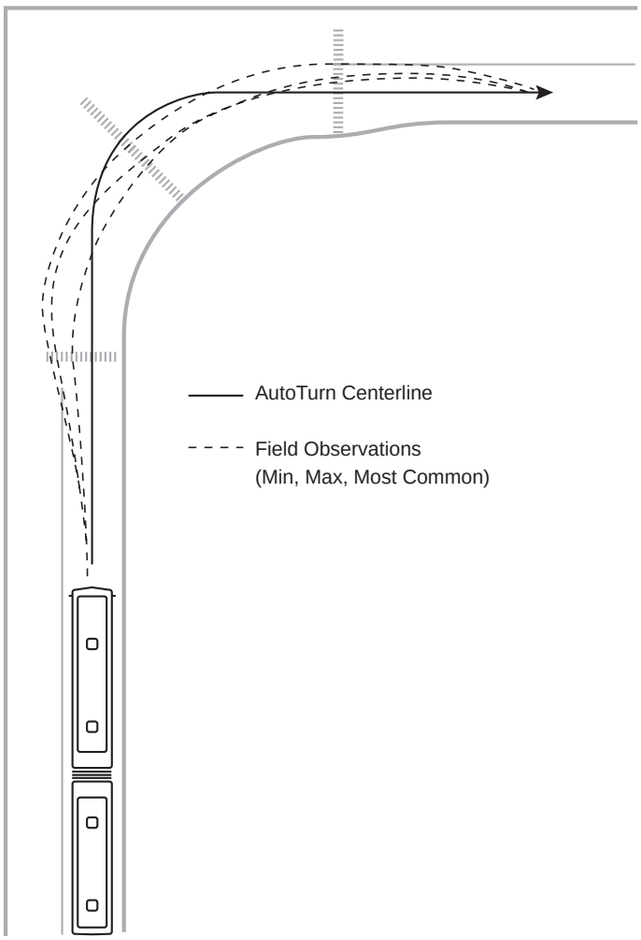


Figure 5-19. Comparison of New Flyer D60 (Articulated Bus) AutoTurn™ Centerline Path vs. Field Observations

Table 5-7. Recommended Corner Radii (*35*)

Width of Approach Lane	Width of Entered Lane		Recommended Curb Radius	
	m	ft	m	ft
3.6 m (12 ft) (i.e., one lane)	3.6	12	15	50
	4.8	16	14	45
	6.0	20	12	40
	7.2	24	11	35
4.8 m (16 ft) (i.e., one lane with 1.2-m (4-ft) shoulder)	3.6	12	14	45
	4.8	16	12	40
	6.0	20	9	30
	7.2	24	7.5	25
6.0 m (20 ft) (i.e., one lane with parking)	3.6	12	12	40
	4.8	16	11	35
	6.0	20	9	30
	7.2	24	7.5	25

turning path produced by design software with field observations. The difference between the two indicates that the designer should consider variability due to driver behavior in right-turn situations.

Table 5-7 shows the recommended curve radii to avoid encroachment into the opposing lane for a 90-degree turn and no truck use.

Table 5-8 summarizes the results of field tests conducted for this study. It shows the minimum radii to avoid encroachment in opposing lanes of traffic for various types of buses and various width of approach

Table 5-8. Minimum Corner Radii to Avoid Encroachment on Opposing Traffic (*34*)

	Case 1	Case 2	Case 3
Width of Approach Lane and Entered Lane, m (ft.)	3.6 (12)	5.7 (19)	3.0 (10)
	Minimum Radius, m (ft)		
<12.2 m (<40 ft) Bus	20 (65)	1.5 (5)	20 (65)
City 12.2 m (40 ft) Bus			
AASHTO	30 (100)	6 (20)	36 (120)
NABI 416	27 (90)	6 (20)	33 (110)
13.7 m (45 ft) Bus			
AASHTO	33 (110)	7.5 (25)	32 (105)
NABI 416	38 (125)	9 (30)	35 (115)
Articulated Bus			
AASHTO	30 (100)	7.5 (25)	30 (100)
New Flyer—D Golf	27 (90)	6 (20)	32 (105)
Intercity 12.2 (40 ft) Bus			
AASHTO	27 (90)	6 (20)	30 (100)
NEOPLAN 34	27 (90)	4.5 (15)	27 (90)

and entered lane widths. In each case, the AASHTO standard is compared to a real-world model bus. Manufacturers include North American Bus Industries (NABI), New Flyer, and Neoplan.

In many situations, especially in densely developed parts of urban areas, it may be necessary to accept some encroachment. Where this occurs, the stop line serving the encroached lanes should be moved back from the intersection.

Bus Movement Across Intersecting Streets

Streets typically have a two percent crown to the curb as part of the drainage system. Where one street intersects another, the crown on the cross street can generate a slight "bump" in the profile of the arterial. This is most apparent in the curb lane, where the bus typically runs. The narrower the cross street, the sharper this effect. The bump can be uncomfortable for sitting bus passengers and potentially hazardous for standing passengers, with the impact on comfort magnified for bus passengers on a street with frequent minor street intersections.

Careful attention therefore should be paid to the details of pavement grades through each intersection. The goal is to make travel in the curb lane of the bus street as smooth and comfortable as possible while protecting the functionality of the drainage design. Normally, the grade-line of the major road should be carried through the intersection and that of the minor road should be adjusted to it. This design involves a transition in the crown of the minor road to an inclined cross section at its junction with the major road by introducing a sag vertical curve on the intersecting street. Superelevation transition lengths for safety and comfort are based on the relative grade differential between the edge of pavement and the centerline profile.

5.3.2 Traffic Engineering Treatments

Traffic engineering treatments vary with the environment where buses operate. They generally include curb adjustments; changes in roadway geometry and pavement markings; parking- and street-use controls; left- and right-turn provisions and controls; one-way street operations; and traffic signal controls, both passive and active. The general goals are to minimize delays to buses and vehicles, improve safety, ensure safe pedestrian and bicycle access to bus stops, and maintain essential access to curbside activities. Complementing these treatments is the need for effective and sustained enforcement of controls and regulations.

- Stop signs or traffic signals should be placed on cross streets that intersect bus routes.
- Curb parking generally has to be accepted, but may conflict in some settings with bus and passenger movements.
- Left turns generally should be accommodated in special turn lanes or otherwise restricted.
- Buses should be exempt from turn restrictions that apply to general traffic.
- Delays at traffic signals should be kept to a minimum by employing passive and active bus controls. This can be achieved by (1) maximizing the available green times along the bus route; (2) shortening cycles as much as practical; and (3) advancing or extending the green time available to buses.
- Minor movement left-turn phases that rarely benefit transit, pedestrians, or bicyclists should be minimized/eliminated.

Curb Use Controls

Loading/Deliveries

Suitable access should be provided for commercial vehicles serving business activities along a street. Street and transit agencies should work cooperatively with commercial establishments to achieve mutually agreeable solutions. Where conflicts exist, transit and curb-access functions must be separated either physically or temporally:

- Loading/delivery functions can be prohibited during peak bus operating periods;
- Loading/delivery functions can be relocated to side streets or alleys or underground docks;
- Buses can operate in a lane other than the curb lane; and
- Buses can operate on alternative streets.

Where loading/delivery functions share the curb lane with bus operations but are prohibited during peak periods, enforcement should be rigorous and the appropriate regime of fines, towing, and penalties applied. Signing should be direct and clearly visible. Chapter 2B of the MUTCD provides specific guidelines on proper regulatory signing.

Enforcement. Effective enforcement of parking regulations is essential—a single parked vehicle in a congested location can significantly delay several buses as they try to merge into the adjacent general-traffic lane to skirt the stopped vehicle. Signing should clarify enforcement restrictions where curb parking exists.

Turn and Street Direction Controls

Right- and left-turn controls commonly are provided to reduce intersection conflicts. Following are some suggested guidelines.

Right Turns. Right-turn lanes should be provided where turning movements are heavy, where the right turns can move on the same phase as the left turn from the cross street, and where space is available. Right-turn lanes are common in suburban settings but are seldom an option in highly constrained settings where they may pose safety problems. Right-turn lanes can be provided by widening, by restriping roads, by narrowing other lanes, or by prohibiting curb parking on intersection approaches.

Left Turns. Left turns along bus routes may be permitted where protected left-turn lanes are provided. Where left-turn volumes are heavy (e.g., more than two to three per signal cycle), speeds are high, or left-turning vehicles must cross more than three opposing lanes, special left-turn phases should be provided.

Left-turn lanes may be provided by diverting the through traffic lanes around, or by recessing paint on a physical median. When through lanes are diverted, the transition distance should be equal to the product of the lane width in feet times the speed in mph. The width of left-turn lanes usually is 3.3 to 3.6 m (11 to 12 ft), but 2.7 to 3.0 m (9 to 10 ft) lanes can be used in restrictive circumstances where buses do not turn. Figure 5-20 illustrates this concept.

Left turns generally should be prohibited where the turns share a lane with through-raffic. Shared lanes reduce capacity about 50 percent, delay through-vehicles, and tend to increase crashes. Prohibitions may be

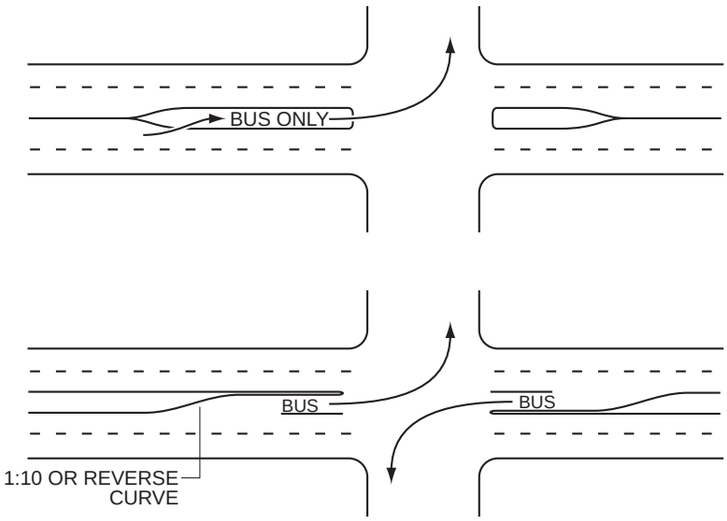


Figure 5-20. Left-Turn Street Controls

appropriate in downtown areas where pedestrian movements are heavy. Where turns are prohibited, suitable alternate routes should be available. Those routes may include (1) upstream or downstream turn lanes; or (2) making three right turns in an around-the-block movement. Strategies such as Michigan's far-side U-turns on divided highways with wide medians, or New Jersey's "jug handles" translate left turns into right turns and achieve two-phase traffic signal operations.

Turn Restriction Exemptions. The most direct route for a bus may not be possible because of left-turn restrictions at intersections. Restrictions often are implemented when there is insufficient space to develop left-turn lanes or when traffic volumes preclude good intersection operation if left-turning traffic is allowed. When left-turn restrictions are a result of traffic congestion, rather than safety, it may be feasible to exempt buses from the restriction without impacting intersection operations (*38*). Similarly, it is common practice to allow buses to pass straight through an intersection in a lane otherwise dedicated to right-turning vehicles, or to exempt buses from right-turn restrictions.

One-Way Streets. One-way streets improve bus, LRT, vehicle, and truck flow. One-way travel reduces conflicts and crashes, simplifies traffic signal phasing, and improves signal progression. They are often found in many downtown areas, and in areas with narrow and closely spaced streets. Travel time reductions of about 25 percent, capacity gains of 20 to 40 percent, and crash reductions of 10 to 50 percent have been achieved through implementation of one-way operations.

There are, however, some disadvantages from a public transportation perspective: (1) service is divided between two parallel streets; (2) the number of curb faces where buses can receive or discharge passengers is cut in half; and (3) passenger walking distances increase where commercial activities are concentrated on both streets. Sometimes, these concerns may be addressed by operating buses two ways on one of the streets in a bus-only contraflow lane.

Traffic Signal Controls

Traffic Signal. Bus delays at traffic signals account for up to one-fifth of overall bus travel times and half or more of all delays encountered. Therefore, adjusting signal phasing, timing, and coordination

to expedite both buses and general traffic will improve bus speed and reliability. The general goal is to minimize person-delay at intersections along a bus route. General guidelines for traffic signal timing and coordination are contained in the ITE *Traffic Engineering Handbook, The Highway Capacity Manual,* and the *FHWA Signalized Intersection Informational Guide.*

Passive Signal Priorities. Passive priorities modify operations to serve transit vehicles better. The goal is to minimize person delay, rather than just vehicle delay, to the maximum extent practical. Signals should be timed to minimize delays to buses by adjusting cycle length, minimizing the number of phases, and using short-cycle lengths where practical.

- Cycle lengths should accommodate peak traffic flows, let pedestrians cross safely, allow a reasonable allocation of green time among conflicting flows, and permit coordination at desired speeds. Within this context, cycle lengths should be as short as possible.
- Shorter cycles reduce red times for buses, especially in bus lanes. This is especially important where buses run at short headways.
  - Green times along bus routes should be maximized by considering the relative numbers of people per lane moved on intersecting streets.
  - On streets with heavy bus flows and light vehicle volumes, the signals should be set for buses. (For example, a street carrying 90 buses per hour and 40 vehicles per hour.)
  - At some locations, special phases may be needed for buses. These could operate on either a fixed time or actual time for buses within background signal cycles.

Active Signal Priorities. Active signal priorities either extend or advance the green time within the established cycles. They should be considered where (1) the person-minutes saved by bus and vehicle passengers along the bus route exceed the person-minutes lost by side street vehicle transit passengers; and (2) the increased queues and delays on the side streets will be manageable (*21*). Important considerations include the following:

- The minimum side street green with priorities must provide adequate time for pedestrians to cross the artery.
- The arterial green should not be advanced and extended in the same signal cycle.
- Where bus volumes are high, it may be desirable to limit bus priorities to every other signal cycle.

Generally, bus headways should not be less than 2.5 to 3.0 minutes where priorities are installed.

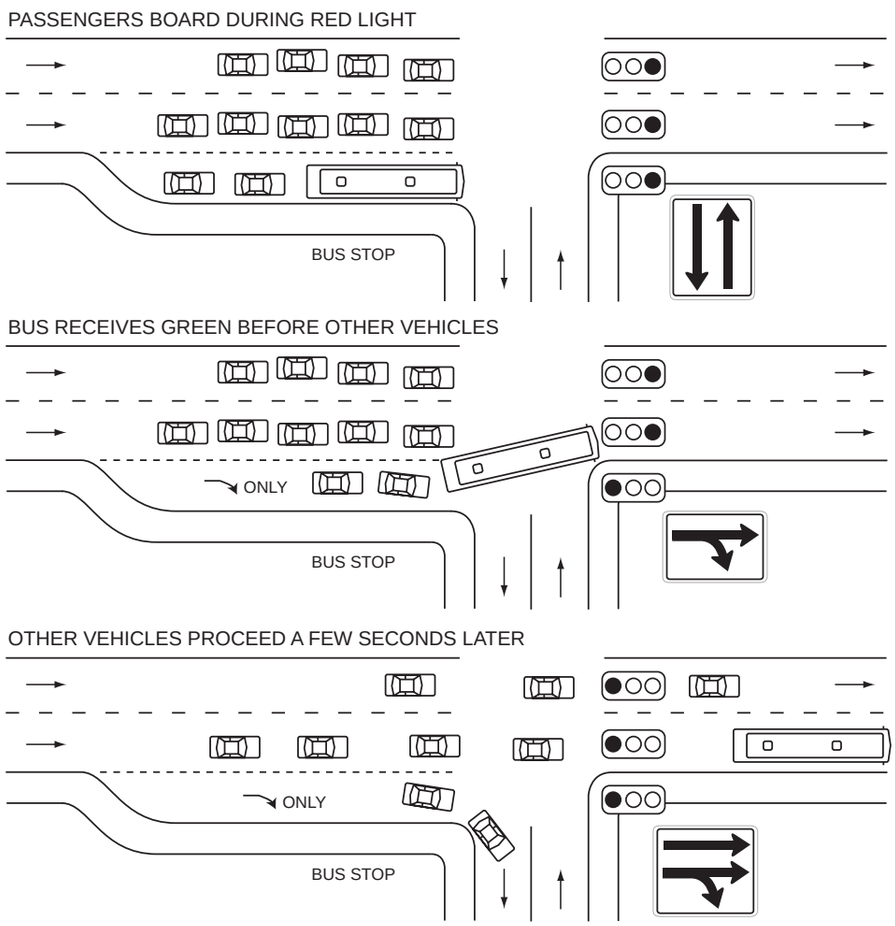
Queue Bypass Lanes. Queue bypass lanes (sometimes called queue jump lanes) allow buses to avoid long queues of vehicles at signalized intersections. A short bus-only lane, coupled with a bus-activated advance green phase enables buses to travel quickly and reliably. The queue bypass benefits bus flow where it is not practical to provide a bus-only lane. Queue jumps should be considered at arterial street intersections when the following factors are present:

- Bus routes have an average headway of 15 minutes or less;
- Traffic volumes exceed 250 vehicles per hour in the curb lane during the peak hour;

- The intersection operates at a LOS D or worse; and
- Land acquisitions are feasible and costs are affordable to construct the required infrastructure improvements.

An exclusive bus lane located between the through- and the right-turn lane, should be considered when right-turn volumes exceed 400 vehicles per hour in the curb lane during the peak hour, or when the right-turn movement operates on a phase with non-conflicting cross-street movements.

Figure 5-21 shows a typical queue jump design and operation. A special right-lane traffic signal provides an advance green indication for the bus before the traffic in the adjacent lane proceeds. During this time, the bus exits from the right lane and merges into the lane to the left ahead of other traffic that had stopped for the signal. The bus activated advance green indication should be about 5 to 10 seconds. The integration of signal timing with the provision of the queue jump lane is essential to safe operations. The pedestrian phase must be considered also. This traffic movement should be coordinated with the traffic operations



Source: TCRP Project D-09 Task 7-4 Bus Pull-Outs, p. 7.

Figure 5-21. Queue Jump Signal (*38*)

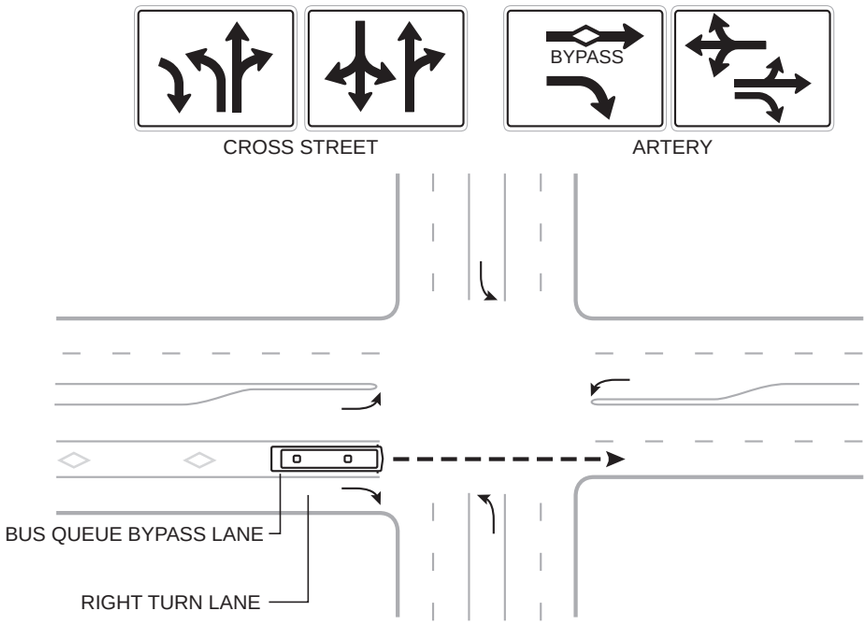


Figure 5-22. Bus Queue Bypass (*38*)

engineers and local law enforcement to ensure that no state, city, or county laws prohibit this movement from the right-turn lane.

Figure 5-22 shows a suggested signal phasing for a condition where the bus queue bypass lane is separate from the bus-only lane. This arrangement provides a special transit signal indication for the bus lane. Buses cannot stop at the intersection to safely use this type of bypass lane.

Queue bypass lanes should be long enough to bypass the observed or expected peak hour queue in adjacent lanes. They should be at least 75 m (250 ft) but can extend up to 300 m (1,000 ft) as needed.

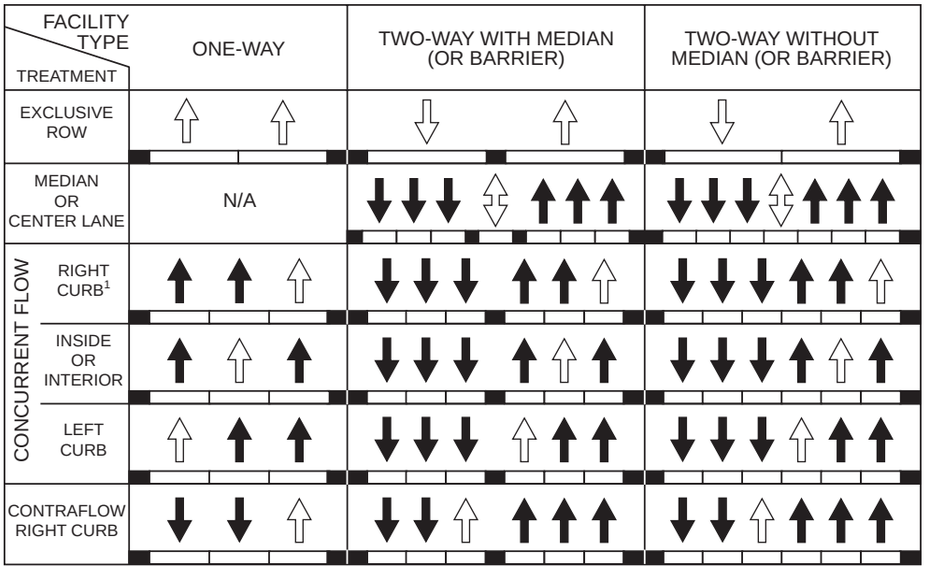
5.4 PRIORITY FACILITIES—PLANNING AND DESIGN

Arterial street priority treatments improve bus speed, reliability, and identity. They may be located and designed in many configurations. Figure 5-23 shows some examples. Treatments vary by (1) placement of the bus lane (curb, interior, or median); (2) direction of flow (concurrent or contra); (3) hours of operation (all day or peak hours); (4) mix of traffic (buses only, buses and taxis, buses and HOVs); and (5) traffic controls required. Preferential treatment also includes median arterial busways and bus-only streets.

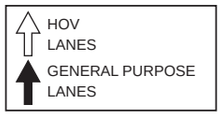
The type of application used will depend upon specific street and local conditions. Transit priority facilities are needed more frequently to resolve operational problems on an existing roadway rather than a new street.

5.4.1 Planning Context

Planning and implementing bus priority treatments requires a reasonable concentration of bus services, visible bus and car congestion, suitable street geometry, and community willingness to support public



[1]Two-way concurrent flow facilities may also operate such that the general-purpose lane is the reversible lane, not the HOV lane. For example, on a six-lane arterial, there would be an HOV lane in the right (curb) lane, three general-purpose lanes, and two opposing general-purpose lanes in the peak period, and the reverse operation in the other peak direction. In off peaks, the road would simply operate with the general-purpose lanes in each direction.



NOTE: Right and left curbs, when referred to in this section of the guide are as viewed from the HOV lane shown. For illustration purposes, the HOV lane is shown operating in one direction for concurrent and contraflow operations.

Figure 5-23. Arterial Street Characteristics (*5*)

transport and to enforce regulations. There is little value in providing bus priority measures where service is poor, costly, or non-existent; where there is no congestion; or where the community does not want to maintain and improve bus service or to enforce bus lanes.

Planning entails a realistic assessment of demands, costs, benefits, and impacts. The object is to identify measures that alleviate existing bus service deficiencies, achieve attractive and reliable bus service, serve demonstrated existing demands, provide reserve capacity for future growth in bus trips, attract auto drivers to transit, support long-range transit improvement and downtown development programs, and have reasonable operating costs.

Need and Justification for Bus Priority Treatments

Within the physical confines of a busy arterial street, it is usually impossible to maintain freeflow traffic conditions at all times. Transit users may experience their share of delay (or even a disproportionate share), and they may create delays to other users of the roadway.

Arterial bus lanes are designed to increase the person-capacity of a roadway by reserving a lane, either part-time or full-time, for the use of buses. When the general traffic lanes become congested, vehicles in the reserved lane would still travel freely. As a result, persons in the reserved lane receive a time-savings benefit compared with persons driving alone. The time savings and service reliability benefits can optimize the efficiency of the bus operation and attract new users from general traffic.

The rationale for design and operation of a facility to provide bus priority over other vehicles (notably private vehicles) may stem from four principles.

- As a matter of public policy, priority may be granted to users who choose the least polluting, most space-efficient, most energy-efficient, and least costly modes.
- Delay inherent in roadway use should be allocated proportionally among all users (i.e., bus passengers should not experience any greater delay than the equivalent trip by private vehicle).
- The public investment in transit service should be protected by ensuring that buses can maintain reliable, efficient schedules.
- Vehicles that maximize person throughput should be given an advantage.

While there is considerable flexibility in the application of these principles, it must be recognized that any advantage to transit usually is coupled with an actual or perceived disadvantage to other roadway users. There are both technical and qualitative aspects to this equation. If a lane is converted from general traffic to exclusive bus use, for example, it will not necessarily be obvious to the motorist in the adjacent lane that the use of that lane by one bus every minute or two is actually the key to maximizing the person-moving capability of the roadway. Similarly, a major investment in transit signal priority could be cost-effective yet imperceptible to motorists and even the bus passengers.

The need and justification for bus priority should consider corridor- or jurisdiction-specific mix of policy, technical, and public perception factors. A priority facility should be assessed on its technical merit as an input to the policy based on the following four categories of system characteristics.

- **Performance—**Many criteria are used to evaluate overall transit system performance. Service frequency, operating speed, person throughput, reliability, safety, line capacity, productive capacity, productivity, and utilization of the system are important measures of the effectiveness of the transit service.
- **Quality of Service—**The quality of service measures the attractiveness of the system. It includes both quantitative and qualitative elements. Quantitative characteristics include coverage, operating speed, headways, reliability, and travel times. Qualitative elements also have a direct effect on the attractiveness of the service. Riding comfort, aesthetics, and cleanliness are among the factors that must be evaluated.
- **Impacts—**A transit service has a direct impact on many factors in its surrounding environment. Both short-term and long-term impacts should be evaluated. Reductions in street congestion, air pollution, and noise are examples of short-term impacts. Long-term impacts include changes in the economic, social, and physical environment.
- **Costs—**Cost include capital, operating, and maintenance costs. Designers should evaluate the capital costs for the improvement as they relate to anticipated benefits, and how they impact operation and maintenance costs. In many cases, transit priority may allow the operator to reduce the number of vehicles operating on a route while maintaining service levels.

The need for transit priority should be continually evaluated, even after the system is implemented. Figure 5-24 shows this iterative process.

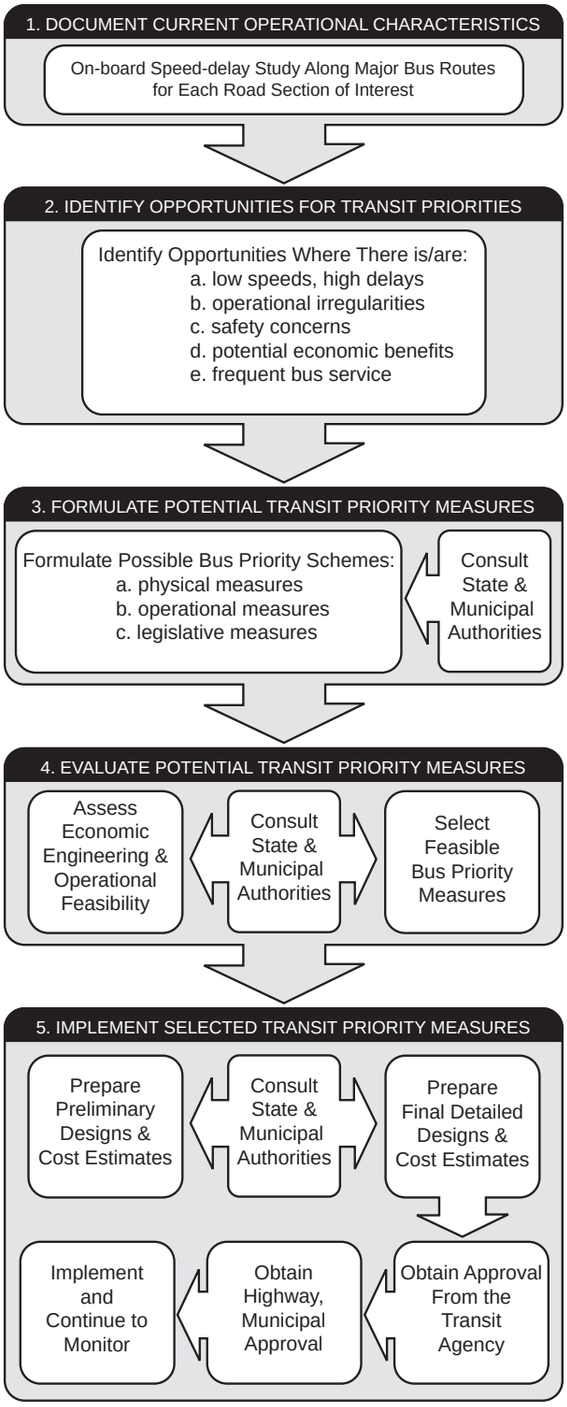


Figure 5-24. Transit Priority Evaluation Process (*7*)

Before any treatment is put into effect, its likely benefits and effects should be analyzed. This is important to provide a sound basis for implementing the treatment and to ensure good operations. A commitment should be obtained from appropriate public agencies regarding enforcement and maintenance. Unless enforcement is strict, frequent violations may occur, undermining the benefits of priority operations. Treatments should be considered when:

- They maximize person flow and minimize person delay over time;
- They result in a net saving in the average travel time per person;
- They expedite bus service without substantially adversely impacting general traffic flow;
- Their costs are reasonable in relation to existing and potential demands and benefits; and
- There is a net economic benefit—the savings in travel time and operating costs exceed the losses sustained by other road users who may be adversely affected.

Selecting the Type of Application

There are two general types of arterial roadway settings where priorities should be considered:

- High-standard, high-speed [65 to 80 km/h (40 to 50 mph)], multilane suburban roads, generally with some limited access (Figure 5-25); and
- Lower-speed, short-block, urban streets generally found in or around centers of concentrated employment such as CBDs (Figure 5-26).

Spot treatments (signal priority, queue jumps, etc.) can be applied on a stand-alone basis or in conjunction with either on-road treatment noted above.

Specific criteria for introducing bus priority measures should reflect specific local conditions. The general guidelines are reasonableness of the proposal, ability to provide net benefits to travelers, and number of bus riders in an exclusive lane should be at least equal to the number of personal vehicle occupants (drivers and passengers) in each adjoining lane for the duration of the priority measure.

Figure 5-25. Typical Suburban Arterial with Bus Bay

Figure 5-26. Typical CBD Street with Bus Lane

5.4.2 General Design and Operating Guidelines

The following guidelines underlie facility design and operation.

- General traffic improvements and road construction should be coordinated with bus service to improve the overall efficiency of street use. Typical improvements include prohibiting curb parking, adding turning lanes, prohibiting turns, modifying traffic signal timing, and providing queue bypasses for buses.
- Curb parking should be prohibited before the curb bus lanes are established, at least during peak hours. The prohibition makes it possible to provide a bus lane without reducing street capacity for other traffic, reduces delays and marginal friction resulting from parking maneuvers, and gives buses easier access to stops. (Where this is not practical, the bus lane should be provided in the lane adjacent to the parking lane.)
- The service requirements of adjacent land uses must be accommodated. Deliveries should be prohibited from bus lanes during the hours that the lanes operate. They can be provided from the opposite side of the street, from side streets, or ideally from off-street facilities. Accommodating deliveries is especially important where contraflow lanes are provided.
- Access to major parking facilities should be maintained. This may require limited vehicle use of bus lanes in the block adjacent to garages.
- Taxi-loading areas should be removed from bus lanes where they would interfere. On one-way streets, the taxi loading areas should be placed on the opposite side of the street.
- Bus routes should be restructured as necessary to make effective use of bus lanes and bus streets. Peak hour one-way bus volumes of about 40 to 75 buses will provide a bus presence without creating excessive bunches.

- Emergency vehicles, police cars, fire equipment, and ambulances should be allowed to use bus lanes and bus streets. Taxis could use bus lanes when peak hour bus volume is less that 40 to 60 per hour.
- Bus priority treatments should reduce both the mean and variability of average journey times. A 10 to 15 percent decrease in bus running time is desirable for bus lanes.
- Extended bus lanes are necessary to achieve significant time savings [0.3 minute per km (0.5 minute per mile)], better service, reliability, and increased ridership. For example, raising bus speeds from 16 to 19 km/h (10 to 12 mph) could save 5 to 6 minutes over the length of a typical bus journey. Additional savings would result from traffic signal priorities.
- Designs should reflect available street widths and traffic requirements. Ideally, the provision of bus lanes should not reduce the number of lanes available to through traffic in the direction of heavy flow. This may entail eliminating parking or reducing lane widths to provide additional travel lanes, eliminating left-turn lanes, or providing reversible lane operation.
- Where buses pre-empt moving traffic lanes, the number of lanes taken should be kept to a minimum. The exception is where parallel streets can accommodate the displaced traffic.
- Bus lanes and streets should provide a strong sense of identity. This can be achieved by using contrasting pavement wherever buses have exclusive use of the lanes all day. Such treatments are especially important for BRT curb bus lanes.
- Access to bus stops should be convenient and safe. Clean, well-lighted stations increase riders' perception of safety. Curb-side stops should allow sufficient space for amenities within the stop or in the adjacent sidewalk. Crosswalks to reach median bus lanes and busways should be placed at signalized locations, wherever possible, and be designed to discourage errant crossings.
- Effective enforcement and maintenance of bus lanes and bus streets is essential. Fines for unauthorized vehicles should be high to discourage illegal use.
- Concurrent flow bus lanes should be at least 3.3 m (11 ft) wide for 2.5-m (8.5-ft)-wide buses; 3.6-to-3.9-m (12-to-13-ft)-wide bus lanes are desirable. Bus streets should be at least 7.2 m (24 ft) wide. When designing a bus lane for one-way flow with barrier curbs on each side, the roadway width should be 6.6 to 7.2 m (22 to 24 ft) to permit passing of stalled buses and illegally parked vehicles.
- Median bus lanes require physical separation from general traffic for maximum effectiveness. Passenger loading islands should meet ADA requirements (e.g., width of 3.0 m [10 ft]).
- Buses should be able to enter and leave priority lanes easily and safely, and other routes should be available for displaced vehicular traffic. New problems should not be created, nor should existing problems merely be transferred from one location to another.
- The simplest, and often most effective, means of terminating a bus lane on an arterial is to bring it to the stop bar at a signalized intersection, then drop the designation at the other side of the crossing. The curb lane on the exit may then continue in general use or be dropped downstream. This technique works for a bus lane in the right, inner, or left lane.
- Another strategy is to make the right lane turn right at the signal while allowing buses to go straight through. The bus lane then can drop, and buses merge into the rightmost general traffic lane downstream

of the intersection. This movement should be coordinated with the traffic operations engineers and local law enforcement to ensure that no state, city, or county laws prohibit this movement from the right-turn lane. Proper signage might help reduce collisions.

- Terminating a bus lane in a mid-block location is simply a matter of signing denoting "Bus Lane Ends" and allowing general traffic to move over and use the lane from that point forward.

The hours that bus lanes are in effect when general traffic is restricted should be clearly defined. The choices are:

- Peak period (peak direction or both directions);
- Daytime (e.g., 7:00 a.m.–7:00 p.m.); and
- Full time (24 hours per day).

Factors influencing the hours of operation include:

- Type of bus lane operation (e.g., normal or contraflow);
- Precedent (local or regional);
- Time, extent, magnitude, and consistency of recurring traffic congestion;
- Bus service frequency and peaking characteristics;
- Demand for use of the lane by others (particularly the curb lane);
- Corridor or system-wide consistency;
- Enforceability and degree of commitment to enforcement; and
- Local or project-specific circumstances.

Peak-period or daytime bus lanes usually apply on weekdays (Monday–Friday) only, since both bus volumes and traffic congestion usually are reduced on weekends. However, some corridors or circumstances may require Saturday or seven-day designation. The need for extended hours should be determined through local study.

Bus Priority Treatments

Designs must be reasonable, not only in how they improve service but also in how they affect traffic and curb access. Community acceptance and support is vital, as are effective enforcement and maintenance.

5.5 PRIORITY LANES

This section contains guidelines for various types of bus lanes. It covers lanes that are located on the right side of roadways, curbside, or in interior lanes operating in normal (concurrent) flow or contraflow. Table 5-9 summarizes the types of bus priority lanes, their application, and their desired lane widths. Table 5-10 summarizes intersection design issues for various types of bus lanes. Section 5.6 presents guidelines for median bus lanes, roadways for busways in the center of roadways, and bus-only streets.

Table 5-9. Applications and Lane Width for Priority Lanes

Type of Priority Lane	Application	Desired Lane Width	Min. Lane Width	Buffer/ Barrier
Bus Use of Shoulders	• Suburban setting • Peak period use • Should be structurally and geometrically adequate	3.6 m (12 ft)	3.0 m (10 ft)	0.9 m (3 ft)
Right (Curb) Lane	• Peak period, peak direction	3.6 m (12 ft)	3.3 m (11 ft)	
Inner Lane (Interior)	• Suburban setting • Suburban commercial setting with high frequency of access or mid-block right turns; allows for continuation of curbside uses • Requires two remaining general traffic lanes • Typically on one-way street pairs	3.6 m (12 ft)	3.3 m (11 ft)	Barrier
Left-Side Normal Flow Lane	• Along divided arterials • Good for express bus services • For bypass of regular and infrequent congestion	3.6 m (12 ft)	3.3 m (11 ft)	Lane

5.5.1 Bus Use of Shoulders (Arterial)

A high-standard multilane arterial pathway for buses in a suburban setting may be provided on paved shoulders. There may be a significant advantage to allowing buses to use the shoulder during congested periods, even if the shoulder is used for other purposes (bike path, parking) during off-peak periods.

Table 5-10. Intersection Design Issues for Bus Priority Lanes

Bus Priority Lane Type	Design Issues
Use of shoulders at intersections	• Usually shared with right-turning vehicles • Queue analysis needed to determine when a shoulder could become a shared lane
Right (curb) lane at intersections	• Lanes can extend to stop bar with right turn allowed from lane/ separate bay, or lane designation terminates in advance of the intersection • Lane designation should end approximately 2.4 m (8 ft) from the intersection per second of green time at 95 percent saturation • Right-turning vehicle blockages at intersections will greatly reduce benefit of facility
Inner lane at intersections	• Reservation of an inner lane for bus poses few restrictions on movements at intersections
Contraflow lanes at intersections on one-way streets	• May require prohibiting left turns or providing left-turn lanes
Median contraflow lanes at divided highways	• Requires prohibition of left turns during hours the lanes are in effect
Left-side normal flow lane	• Requires left turns to be prohibited

Design Considerations

Shoulders used by buses should be structurally and geometrically adequate. The shoulder pavement strength must be designed to reflect regular use as a traveled lane. This generally requires the shoulder pavement to be consistent with that of the adjacent general-purpose lanes. The traveled portion of the shoulder should be no less than 3.0 m (10 ft) wide and preferably 3.6 m (12 ft) wide. In addition to the traveled portion, an additional paved "shoulder" of at least 1.0 m (3 ft) width should be provided as a buffer between the edge of the travel lane and any obstructions, piers, sign supports, walls, ditch edges, or guard rails. Specifications such as sight lines, illumination, and offset from obstacles must be met by the shoulder lane just as if it were a normal traffic lane.

The shoulder should revert to its function as a breakdown facility during uncongested periods, while buses use the general-purpose lanes. Where an incident or a stopped car blocks the shoulder during times of bus lane operation, buses must merge into the rightmost general traffic lane to skirt the obstacle, then re-enter the shoulder downstream of the blockage. Designers should carefully consider signing and pavement marking, since a shoulder bus lane changes functions by time of day.

Even though a substantial signing and enforcement effort should ensure that parked vehicles are not left on the shoulder during bus lane operation, regulations for no stopping and no parking should be established. A "sweep" of the lane by tow trucks at the start of the bus lane period may be required.

Intersection Treatments

Most suburban arterials that have enough congestion for shoulder bus lanes to be considered have dedicated right-turn lanes at intersections. The shoulder, therefore, typically becomes the right-turn storage lane as the intersection is approached. Thus, the bus-only lane is not continuous across the intersection. Since the shoulder is structurally capable of accommodating the traffic loads, the design issue is: Where does the lane becomes available to right-turning vehicles? Procedures for analyzing the standard length of the right-turn queue should define this point. Refer to the *Highway Capacity Manual* to estimate the amount of storage space needed to accommodate vehicles arriving at a signalized intersection during the red phase of the cycle.

The shared bus/right-turn lane should be clearly delineated by pavement markings and (optionally) signing. Buses approaching that point can continue through in the right lane or merge left to bypass any queue that may develop in the turn lane (Figure 5-27). At the intersection, all vehicles other than buses should be required to turn right, and buses should proceed through to a far-side bus stop.

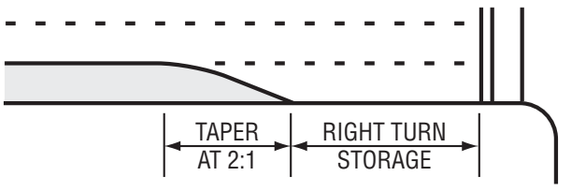


Figure 5-27. A Shoulder Lane Approaching a Signalized Intersection with a Right-Turn Lane

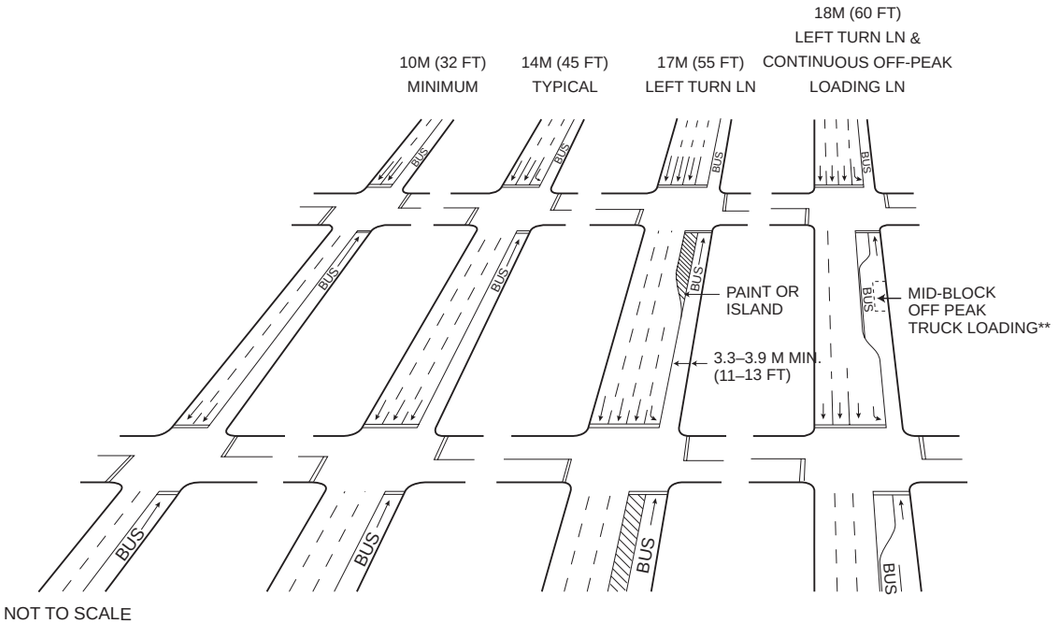
Figure 5-28. Right Curb Bus (HOV) Lane, Toronto

5.5.2 Right (Curb) Lane

Normal (concurrent) flow curb bus lanes are the most common type of priority treatment. They have been installed to expedite transit operations in CBDs by segregating buses from other traffic. These lanes are the easiest to implement and have the lowest installation costs since they normally involve only pavement markings and street signs. They may operate throughout the day or only during peak hours. They have minimal impact on intersecting driveways and street routings, but usually they are least effective in terms of travel time saved, are difficult to enforce, and affect curb access. Right turns, when permitted, conflict with bus flow.

Generally, the right curb bus lane is reserved for bus use during weekday peak periods in the peak direction. Curb parking is still available during the midday, evenings and weekends. Removing buses from moving traffic isolates them from vehicles, minimizing the impact of bus operations on the remaining general purpose lanes (see Figures 5-28 and Figure 5-29).

Figure 5-29. Stopped Vehicle Obstructing Bus Lane, Toronto



Normal Flow Curb Bus Lane Designs for Two-Way Streets

NOTES:
* Add 0.6–0.9 M (2–3 ft)in areas with heavy pedestrian flow.
** ACT—provide loading from highway lane side.
Can also serve as bypass lane.

Figure 5-30. Normal Flow Curb Bus Lane Designs for Two-Way Streets

Design Consideration

The bus lane width should be no less than 3.3 m (11 ft)—preferably 3.6 m (12 ft)—even if this requires re-allocating width from other lanes. A 3.9-m (13-ft) lane should be provided where space is available. Figure 5-30 shows examples of bus lane design and envelopes for two-way streets of varying width. The width of the curb lane should be increased if bicycles also use the lane. Refer to the AASHTO *Guidelines for the Development of Bicycle Design Facilities* (*4*) for appropriate lane widths in that shared situation.

The main concern with curb bus lanes is competition for use by other vehicles, to the point that the lane is rendered ineffective as a bus priority facility. Demands for the curb lane use, particularly in a congested urban/CBD environment, can come from:

- General traffic;
- Parking/stopping;
- Deliveries;
- Taxi stands;
- Bicycles;
- Right turns and queues (both at intersections and mid-block);

- Service/maintenance vehicles; and/or
- Bus stops.

It can be a challenge to keep the curb lane clear of stopped or parked vehicles for uninterrupted bus movement. Fronting retailers in particular are often concerned about the provision and retention of on-street parking. For these reasons, it is common to lift the bus lane designation during off-peak periods and to allow other uses of the curb lane. Consideration must be given, however, to the need for buses to stop and serve passengers throughout the day.

Turning movements that would impede bus service should be eliminated. Ideally, right turns should be prohibited where more than 300 persons per hour use a conflicting crosswalk. Left turns by general traffic should be prohibited on streets without provisions for left turns.

Signing, regulations, effective enforcement penalties, and an active towing strategy are needed during the period of bus lane operation. Periodic review of the affected corridor is warranted to ensure that adequate provisions are made for accommodating parking, delivery, service, and operational needs of the street while preserving the functionality of the bus lane.

Intersection Treatments

The bus lane can extend to the stop bar, with right turns allowed from the lane or from a separate right-turn bay. Alternatively, bus lane designation can terminate in advance of the intersection. This treatment is common outside North America.

The length of the set-back of the end of the bus lane (to permit right turns) from a signalized intersection is an operational and design issue that has been studied in detail in the United Kingdom, where curbside bus lanes are common. A fine balance should be achieved between providing bus priority and accommodating the right-turn needs of vehicles. The guideline established by Oldfield et al. (1977) suggests that the bus lane should end (and right-turning vehicles should be allowed to enter the right lane) approximately 2.4 m (8 ft) per second of green time at 95 percent saturation. The set-back can be reduced to 0.9 m (3 ft) per second of green at 70 percent saturation. For a 40-second green time, these distances become 90 m (300 ft) and 36 m (120 ft), respectively.

Right-Turn Provisions—Shared Lane Use for Right Turns

Allowing right-turning vehicles to use the curbside bus lane on the approach to an intersection effectively terminates the bus lane at the point at which other vehicles can use the lane. There is little benefit to implementing a curb lane bus lane if the right-turn lane approaching an intersection is regularly blocked with queued vehicles. To minimize the disruption to the through-movement of buses, the following options should be considered.

- Ban right turns during the period of bus lane operation.
- Direct right-turning vehicles to unsignalized cross streets (for example, in a grid network, turns can be made one street in advance of a major crossing arterial then through the grid to the desired cross street, thereby allowing right turns to be banned at the major arterial).
- Allow right turns on the red phase of the signal (right turn on red).
- Use a short signal cycle to provide frequent opportunities for right-turning vehicles to enter the cross street.

- Provide a free lane away from the turn on the cross street, so that right-turning vehicles can move easily into the cross street.
- Avoid a double left turn in the opposing direction on the main street, so that right turns and opposing lefts can occur simultaneously where two lanes are available to the cross street.

Allowing vehicles to turn right from the rightmost general purpose lane (the second lane) is not recommended and should be discouraged for safety reasons.

Right-Turn Provisions—Separate Lane for Right Turn

One approach is to provide a separate right-turn lane to the right of the bus lane. The length of the lane should be adequate to store the maximum queue, so that it does not spill back into the bus lane. A break in the pavement marking, supplemented by advance guide signs, should be provided to direct turning vehicles safely across the bus lane and into the turn lane. On one-way streets another option may be considered. The approach is to use alternating bus-only lanes and right-turn lanes on downtown streets crossing a series of one-way streets. The bus-only lanes are located in blocks where the upcoming cross street is one-way to the left (thus no right-turn conflicts); in the next block the bus has the option of traveling in the right-turn-only lane and proceeding through the intersection, or leaving the right-turn-only lane to bypass a right-turn queue blocked by pedestrians. To be effective in a downtown environment, block lengths must be relatively short [less than 150 m (500 ft)], since the bus stops are now located every other block.

5.5.3 Inner (Interior) Bus Lane

A bus lane may occupy the second lane from the curb, leaving the curb lane free for parking, deliveries, bicycle use, right turns and storage, or bus stops. This arrangement can overcome many of the drawbacks of a curbside bus lane. Examples of interior bus lanes include Ottawa and Washington Street in downtown Boston (Figure 5-31).

Inner bus lanes generally are more applicable in the urban/CBD settings rather than in suburban environments. Curb lane conflicts on suburban roads usually are limited to right-turning vehicles and queues,

Figure 5-31. Bus Lane, Ottawa

Figure 5-32. Dual Bus Lane Madison Avenue, New York City

which can be accommodated by providing additional right-turn lanes. A bus lane through a suburban commercial strip with frequent entrances and a high volume of mid-block, right-turning vehicles, however, might operate better in the second lane.

Design Considerations

Ideally, at least two lanes should remain available for general traffic. Since the curb lane has little functionality for through-traffic, inner lane bus lanes require an eight-lane, two-way roadway or a four-lane, one-way street. For this reason, inner lane bus lanes are most common on one-way street pairs in CBD settings.

Dual bus lanes are a special case of inner lane bus operation. They can be used where street width and circulation patterns permit, bus volumes are very high (over 100 buses per hour), and a mix of express and stopping buses exceeds the capacity of a curb bus lane at stops. This arrangement is used along Madison Avenue in midtown Manhattan during afternoon peak hours (Figure 5-32), during which all right turns are prohibited.

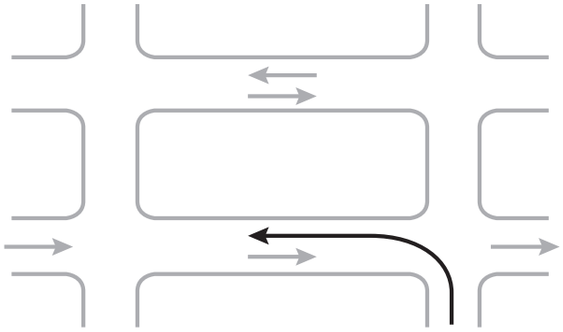
The width of an inner bus lane should be at least 3.3 m (11 ft)—preferably 3.6 m (12 ft)—even if that requires re-allocation of width from other lanes. The width of the curb lane could be reduced to 3.0 m (10 ft) as a first step.

Allowance should be made for motorists to cross the bus lanes to the curb lane. For mid-block driveways and parking, vehicles can be allowed to cross (but not drive in) the bus lane. Designated zones for where vehicles are allowed to cross the bus lane to gain access to a right-turn lane can be marked ahead of the intersection (see Signs and Pavement Marking, later in this chapter). The legal framework must be in place to allow the regulation and enforcement of such movement.

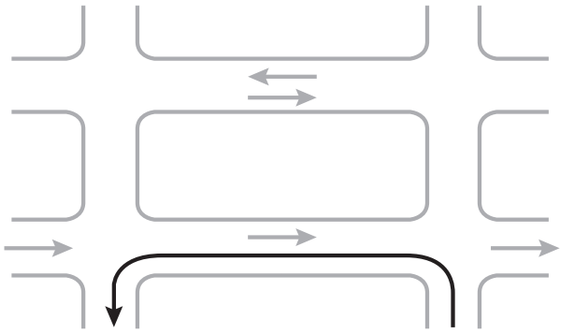
Intersection Treatments

Reservation of an inner lane for bus or HOV use poses few restrictions on movement at intersections. Buses will move straight ahead in the lane, or shift to other lanes to make right or left turns. Curb parking on the approach to the intersection should be removed to let right-turning traffic weave across the bus lane and use the curb lane to make stops.

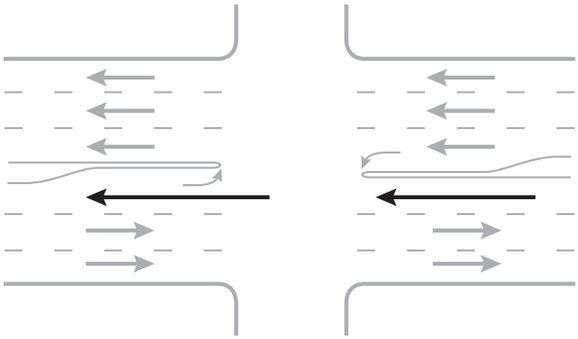
Some applications depend on the vehicles having doors on either side, or on the locations of bus stops.



A) KEEP TO RIGHT ON ONE WAY STREET



B) KEEP TO LEFT ON ONE WAY STREET



C) TWO-WAY DIVIDED ARTERIAL

Figure 5-33. Contraflow Bus Lane Options

5.5.4 Contraflow Bus Lanes

Contraflow bus lanes enable buses to operate opposite to the normal traffic flow on one-way streets or on multi-lane roadways with physical barriers between opposing directions of travel (Figure 5-33). They can enable buses making turnarounds to move quickly. “Right-side lanes” keep to the right of the opposing general purpose lanes and “left-side lanes” to the left.

Contraflow Lanes on One-Way Streets

On one-way streets, bus lanes can be provided in the direction opposite to the main flow. These lanes enable buses to operate opposite to the normal traffic flow on one-way streets. They retain existing bus routes when new one-way street patterns are instituted, allow new bus service on existing one-way streets, use available street capacity in the off-peak directions of flow, and permit passenger loading on both sides of one-way streets, thereby increasing curbside bus loading capacity. Buses are removed from other traffic flows and are unaffected by peak hour queues at signalized intersections. The lanes provide a high degree of bus service reliability. They can speed up radial express bus service along one-way arterial street couplets leading to the city center; allow two-way bus service on one-way downtown streets; and provide more direct bus routings with savings in bus miles, hours, and operating costs. They are "self-enforcing" since the presence of violators is easily detected; thus, they are an effective means of eliminating bus lane violation. The lanes normally operate throughout the day, although "peak-hour" contraflow lanes have operated in Chicago and New York.

If the one-way pair has been changed from a two-way system, contraflow bus lanes may be desirable or necessary to maintain traditional bus stop or routing patterns.

Design Considerations

For a contraflow bus lane to be effective, at least 20 to 30 buses should be using it during peak hours. There should also be at least two-moving general traffic lanes in the peak hours. Curb parking and loading should be prohibited from the lanes. Where progression favors traffic in the opposite direction, signals should ideally be spaced far apart [at least 150 m (500 ft)] to minimize frequent stops. The basic design will vary depending upon the amount of space available. Key considerations are:

- Providing left-turn lanes for general traffic (or prohibiting left turns);
- Providing space for goods delivery and services (when it cannot be provided across the street or in other locations); and
- Providing space for passing stopped buses (either bus bays or dual bus lanes).

Figure 5-34 shows examples that address some of these requirements. The traffic in roadway envelopes reflects the number of general purpose lanes and whether left-turn lanes are provided.

Contraflow bus lanes should be at least 3.6 m (12 ft) wide. However, a 3.9-to-4.2-m (13-to-14 ft) lane is desirable to allow buses to pass around pedestrians who step off the curb. The lanes could be narrowed by 0.3 m (1 ft) in short constrained areas.

Designers should carefully consider the planned strategy for bus operations, since there is little or no opportunity for a bus in a single contraflow lane to pass a stopped or disabled vehicle. If several buses are operating in a platoon, the last bus is governed by the "worst case" of the preceding stopped buses. If there are heavy boarding volumes or disabled passengers to be served, the risk of a following platoon backing up across the cross street should be considered. Where curb space is available, a bus bay can be used to minimize such conflicts and provide operational flexibility.

Provisions for passing stopped or disabled vehicles are needed where bus volumes are high or the lanes operate over a considerable distance. These conditions may call for dual contraflow lanes. A section of the Los Angeles Spring Street contraflow lane, which carries more than 250 buses during a two-hour evening peak period, was redesigned to permit passing of stopped buses (Figure 5-33).

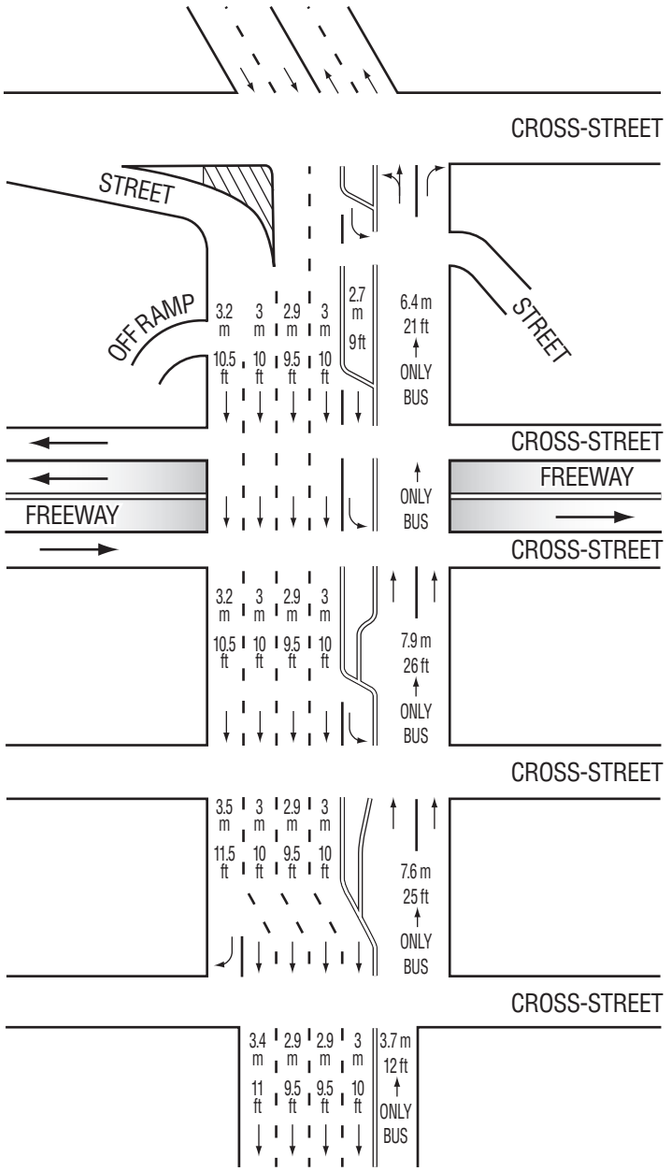


Figure 5-34. Spring Street Contraflow Lane (Los Angeles) (*3*)

Contraflow lanes should be designed for 24-hour use, rather than temporary or peak-only operation. Since the right-side lanes restrict the use of a two-way street, it is not necessary to physically separate the bus lane from the opposing traffic. If desired, however, the opposing lanes may be physically separated by a raised concrete strip, flexible delineators, or pylons where lane width permits (3.9 to 4.8 m [13 to 16 ft] for a single lane). These islands can separate bus and car traffic and provide refuge for left turns.

Contraflow lanes that keep to the left of the general traffic flow (left-side contraflow bus lanes) require physical separation, however, because in terms of motorist expectations, they are on the "wrong side." The bus lane should be wider—up to 4.2 m (14 ft)—where separation is in the form of a concrete wall, pylons, or cones. Buses should operate with headlights on or parking lights flashing where legal while in a

Figure 5-35. Signing and pavement markings for Contraflow Bus Lane on Spring Street, Los Angeles (*15*)

contraflow lane to alert oncoming motorists of the opposing traffic on what might otherwise be expected to function as a one-way street. Figure 5-35 illustrates signing and pavement marking used on the the Spring Street contraflow bus lanes in downtown Los Angles.

Vehicles other than buses should not be allowed to use or block the bus lane at any time. No stopping/no parking regulations should be in effect. Delivery vehicles may sometimes be allowed to use the lane during off-peak hours, although this practice should be discouraged.

Contraflow lanes have a varied accident history. When the lanes operate on a street that was previously two way, total accidents drop. When the lanes operate on a street that previously was one way, an increase may occur. The main contributing factor to accident increases is the inability of crossing pedestrians or motorists to recognize a street's "wrong way" operation since they don't expect traffic to come from that direction. When crossing, individuals may scan for traffic in the general traffic direction and fail to look for contraflow traffic. These perceptual deficiencies occur because the design of contraflow facilities violates basic driver and pedestrian expectancy.

Pedestrian safety can be improved by frequent opportunities to cross at signalized crosswalks and strict enforcement of jaywalking ordinances. An animated eyes symbol may be added to the pedestrian signal heads in order to prompt pedestrians to look for vehicles in both directions. Figure 5-36 illustrates the animated eye symbol with white eyeballs that scan from side to side.

In busy pedestrian environments where people frequently cross streets mid-block, there is considerable risk that they will step off the curb into the contraflow bus lane while concentrating on finding a gap in the "one-way" flow of vehicle traffic. This is a particular risk where the bus lane is retrofited to what was once a one-way street. In such a situation, a physical barrier should be placed at curbside to channel pedestrian crossings to signalized crosswalks, and to prevent mid-block crossings. Designers should consider the

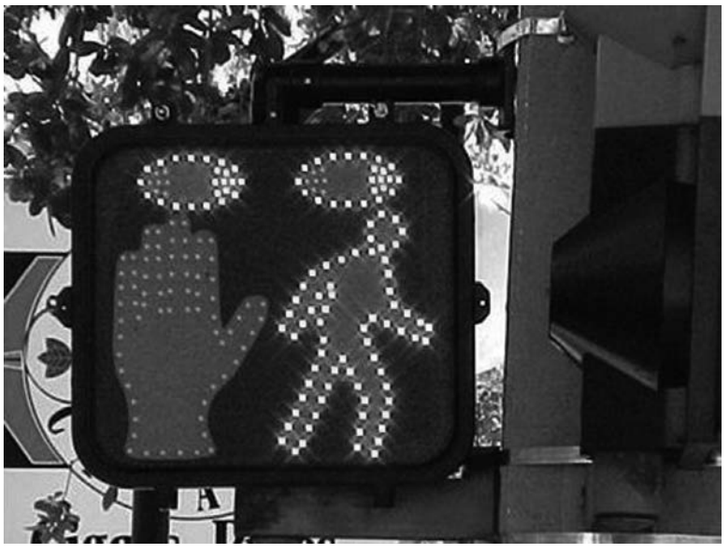


Figure 5-36. Photo of Animated Eyes on a Pedestrian Signal Display (*17*)

design of the barrier so that it is safe and attractive and fits into the streetscape plan. The lanes should be at least 3.9 to 4.2 m (13 to 14 ft) wide to provide space to let buses maneuver around errant pedestrians.

Intersection Treatments

Contraflow lanes violate the expectations of pedestrians and motorists. The risk that motorists will turn without looking at the bus lane, and either inadvertently enter the bus lane in the wrong direction or cross the lane while heading for a gap in the main flow, can have serious consequences. Channelization, turn restrictions, signing, line and pavement marking, streetside guidance, and public education all serve to minimize this risk. Left turns from opposing traffic lanes should be prohibited unless protected lanes are provided. A special turn phase may be provided if desired.

Median Contraflow Lanes on Two-Way Streets

In a suburban arterial setting where there is a directional imbalance between flows during peak periods on divided highways and there is little opportunity to assign one of the peak-direction lanes to bus priority use, it may be possible to "borrow" the inner lane from the off-peak direction for use as a peak-period bus lane. For example, a brief segment of contraflow lane could be used near a median island or bus stop for a single reversible lane (see Figures 5-37 and 5-38).

Design Consideration

A median contraflow lane is best suited for use by express or limited-stop buses that do not stop, and thus do not require stops or stations. This allows the buses to operate contraflow on roadways with narrow median dividers. Bus stops, when provided, require a median width of 3.0 m (10 ft), since stops normally are located at intersections. Where left-turn lanes are common, a median separation of at least 6.6 m (22 ft) should be provided. Figure 5-39 shows two conceptual designs with traffic controls.

At least two lanes should be available for general purpose traffic alongside the contraflow bus lane. The bus lane should be physically separated from the oncoming general purpose lane by daily placement of pylons or

Figure 5-37. Median Contraflow HOV Lane, Honolulu, Hawaii

pop-up flexible delineators. A median should separate opposing directions of traffic when the median width allows. Far-side bus stops can be provided within the median area. To avoid head-on collisions with left-turning vehicles, conflicting left-turning movements should be prohibited during the hours of contraflow operation.

Buses should operate with headlights on or parking lights flashing (when permitted) while in the contraflow lanes to alert oncoming motorists of the (unusual) opposing traffic. Local bus services should remain in the outside curb lanes.

Access to and from the ends of the median contraflow lane can be provided by median crossovers. The design of the crossover will depend on the speed of the traffic.

Designers should consider possible changes in traffic patterns over time. A commitment to median contraflow lanes (e.g., through construction of median bus platforms and shelters) is premised on the directional imbalance during peak periods as a long-term operating condition.

Figure 5-38. Exclusive Transit Lane in Median

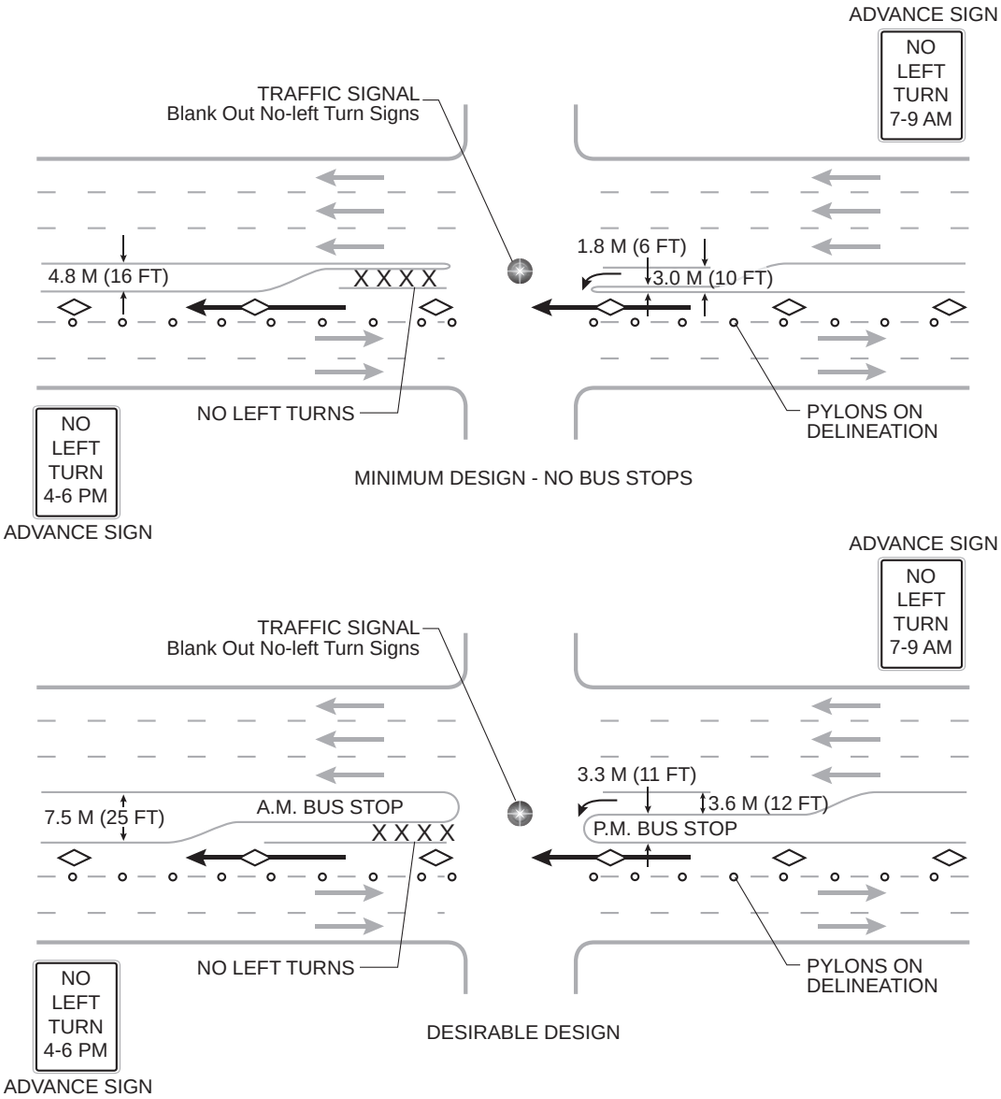


Figure 5-39. Contraflow Bus Lane Design

On undivided roadways with directional imbalances of traffic, additional lanes should be provided in the peak period in the heavy direction of travel. The curb lane could be converted to bus-only use. Alternatively, only express buses can use a lane in the opposite direction.

Intersection Treatments

Left turns in either direction from an arterial should be controlled using protected phases at signalized intersections. However, when the contraflow lanes operate, the left turns from the off-peak direction should be prohibited to avoid possible head-on collisions with buses. Cones should be placed to make entry into the lanes difficult. Advance warning signs and variable message (or blank-out) "No Left Turn" signs should be placed at the intersections. Special signing and pavement markings are desirable to guide side-street vehicles turning left into the arterial from crossing streets into the general-purpose lane rather than the oncoming bus lane.

Figure 5-40. Median Concurrent Flow (Left-Side) Bus Lane, Paris, France

5.5.5 Left-Side Bus Lanes

Left-side bus lanes are sometimes provided in the lanes adjacent to the center island median strip on a high-type, divided, multi-lane arterial. The lanes are generally used by express or limited stop bus service, while local service is retained in the curb or inner bus lanes. The lanes may operate at all times, or just during the peak hours.

Median concurrent flow (left-side) bus lanes operate in Paris, France (Figure 5-40). Left-side bus lanes are under construction along Superior Avenue in downtown Cleveland as part of the Euclid Avenue BRT project. Buses will have doors on both sides, allowing for passenger stations on the median area.

5.5.6 Signs and Pavement Markings

Signs and pavement markings are the key methods of informing bus drivers and motorists alike of the existence of a transit facility in mixed traffic. The *2009 Manual on Uniform Traffic Control Devices* (*16*) has specific signing and marking standards for reserved lanes. While most relate to HOV and light rail facilities, these standards could and should be applied to bus lanes. For example, the elongated diamond used on HOV lane signs may be applicable to bus lane signs if the HOV and bus lane are shared. Word messages are used for bus lanes.

Signs

Curbside Preferential Lane Signs (MUTCD 2009 Sec. 2G.03)

Ground-mounted preferential lane signs should be used in conjunction with overhead preferential lane signs, discussed in the following section. Preferential lane sign spacing should be determined by engineering judgment based on prevailing speed, block length, distance from adjacent intersections, and other considerations. Figures 5-41 and 5-42 show preferential lane signs. Appropriate "No Parking"/"No Stopping" signs must be prominent at the curbside for effective curb bus lane operation.

Figure 5-41. Curbside Preferential Lane Signs (*16*)

Intersection Lane Control Signs (16)

Intersection lane control signs should be mounted overhead unless the number of through lanes on an approach is two or less. A transit priority lane should have a supplemental "BUS LANE" R3-5d plaque (Figure 5-43).

Overhead Preferential Lane Signs (16)

Overhead preferential lane signs should be used in conjunction with the ground-mounted preferential lane signs (see Figures 5-40 and 5-41).

Reversible Lane Signs

Conventional MUTCD signs may be used for buses operating in reversible lanes. Designers should consider the use of dynamic overhead control signals to emphasize the operational rules in place at any given time.

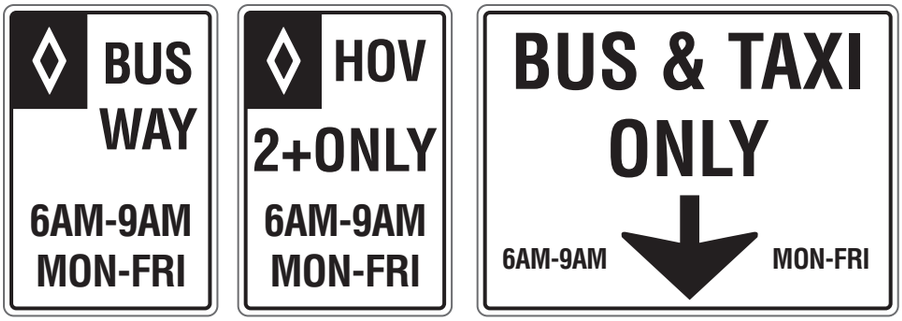


Figure 5-42. Overhead Preferential Lane Signs (*16*)

Contraflow Lane Signs

For contraflow lanes of any type (right curb, left curb, median), conventional signs should be used at frequent intervals, particularly at cross streets (including advance signs on cross streets approaching the contraflow corridor) and major driveways. Overhead signs, lane-use control signs where applicable, and flashing lights on preferential lane signs should emphasize the contraflow operation. Electronic signs or arrows may be placed on the front of the buses themselves, and activated while in the lane. Pedestrian crosswalks should be traffic signal-controlled.

Pavement Markings Between Intersections

Preferential Lane Word and Symbol Markings (16)

Where a lane is assigned full or part time to transit vehicles, the preferential lane markings should consist of the words BUS ONLY. The lettering should be white and positioned laterally in the center of the transit lane, and words must be oriented in the direction of travel. Marking spacing should be based on the prevailing speed, block lengths, distance from intersections, and other factors and may be spaced as close as 24 m (80 ft)

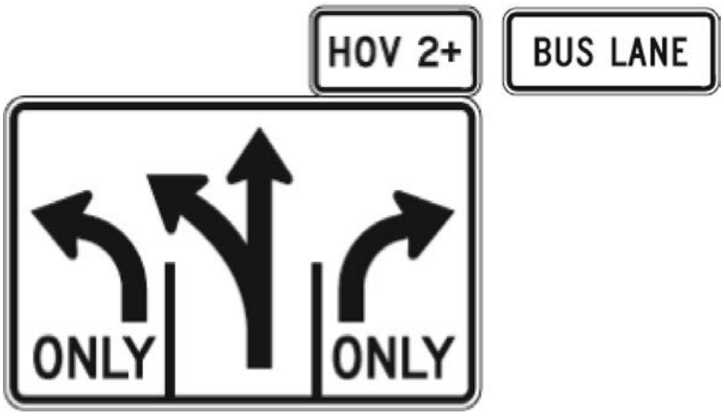


Figure 5-43. Intersection Lane Control Signs (*16*)

Figure 5-44. Typical Lane Word Marking Layout (*16*)

apart. Signs or signals should also be used in conjunction with the lane word markings. Engineering judgment should determine the need for supplemental devices such as tubular markers, traffic cones, or flashing lights. Figure 5-44 shows an example of elongated letters.

Colored Pavement

Some cities overseas use colored pavement, either for the entire reserved lane or in limited use at lane thresholds and intersections (e.g., Edinburgh's "green lanes"). Given the widespread acceptance and effectiveness of the practice, designers may want to consider it, although concerns about cost, maintenance, and standardization must be addressed. Since colored pavement is not included as a traffic control device in the MUTCD, this use must be approved as an experimental use by FHWA.

Designers may also consider emphasizing the pavement message by periodic use of colored "patches" (Figure 5-45). An Australian application has been found to be effective in reducing bus-lane violation.

Figure 5-45. Bus Lane Pavement Marking—Australia (*29*)

Figure 5-46. Bus Lane Pavement Marking—New York City (*8*)

This red marking in the United States is not compliant with the MUTCD. This type of treatment needs FHWA approval as an experimental use. New York City has approval from FHWA for the experimental use of the colored pavement as a traffic control device. Some examples of this are shown in Figure 5-46.

Preferential Lane Longitudinal Markings

The preferential lane markings listed in Table 5-11 should be used in conjunction with preferential lane signs discussed. If there are two or more bus lanes, they should be separated with a normal broken white line. Figure 5-47 shows some examples of typical pavement markings. For the complete range of markings see Part 3 of the MUTCD.

Colored Lane Markings

Bus lanes or facilities may be highlighted with colored lines or curbs. Many of New York's bus lanes featured a red stripe (outlined in white) parallel and adjacent to the curb (Figure 5-48). Similar lines have been used in other jurisdictions, but this use in not included in the MUTCD. (*16*)

Intersection Treatments

A bus lane at a signalized intersection should have a dedicated traffic signal head marked as such where the bus lane operates at all times and right turns do not share the bus lanes. Designers may consider the use of special "bus" signal heads.

Pedestrian Crosswalks

Where pedestrians cross at designated locations under protected signal phases, there are no conflicts with transit operations. At uncontrolled crossings, however, situations can arise when pedestrians attempt to cross or people run to catch a bus at a stop. Pedestrians may try to cross through stop-and-go traffic without realizing that the curb lane is a reserved bus lane with free-flow bus operations. They may check traffic and step off the curb into a contraflow bus lane without looking for buses. Designers should consider the risk of such movement and implement necessary signing, sidewalk or median barriers, or

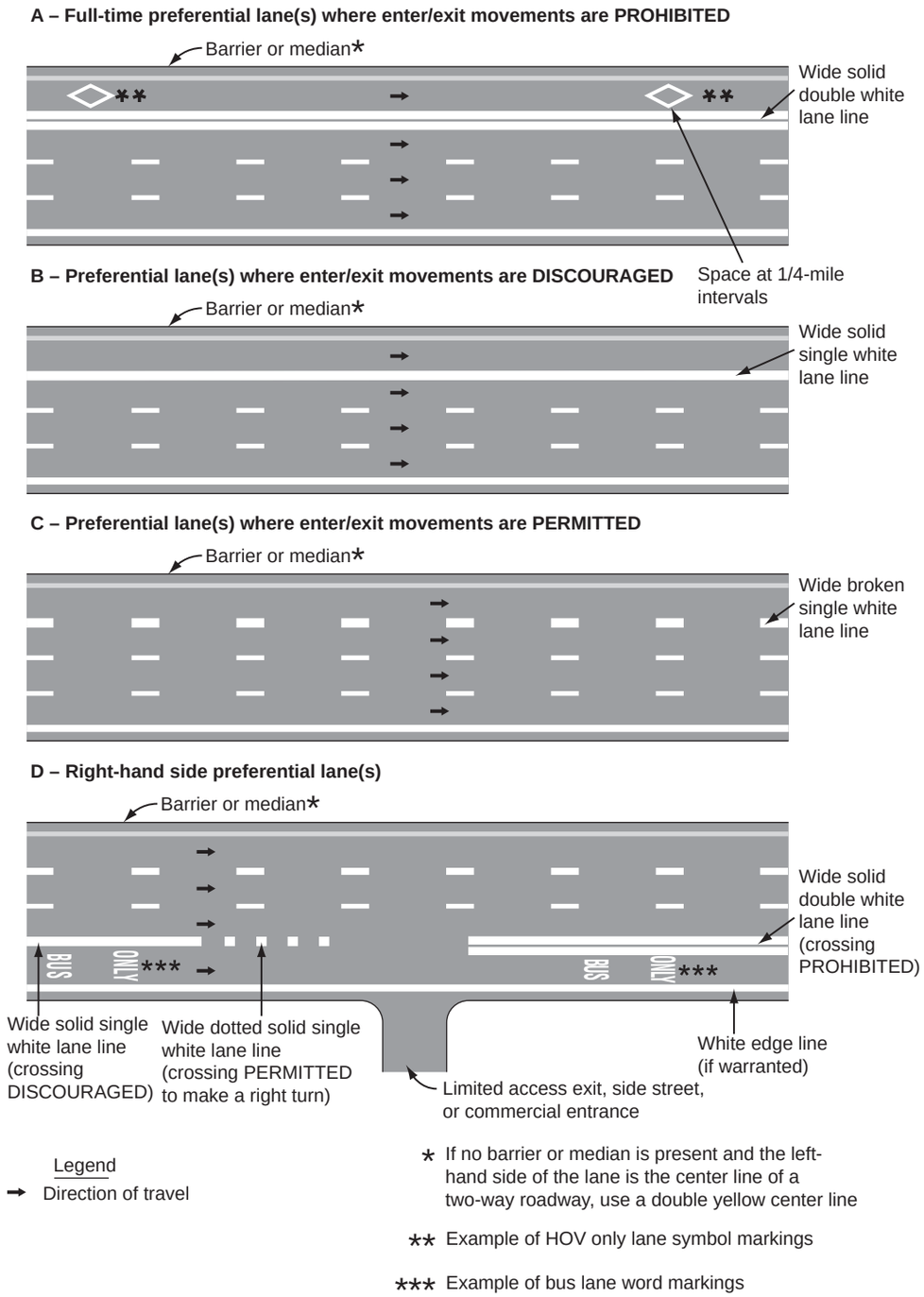


Figure 5-47. Typical Markings for Preferential Lanes (*16*)

improved pedestrian crossing opportunities (pedestrian islands, mid-block crossings, a grade separated crossing, etc.). Difficulties with transit and crosswalks include near side bus stops that obscure the view of approaching drivers of crossing pedestrians and vice versa; proximity to a bus so close to the crosswalk that drivers may not notice a pedestrian in front of them, and blocking crosswalks while buses are waiting to proceed through an intersection.

Table 5-11. Preferential Lane Longitudinal Markings

Type of Preferential Lane	Left-Edge Line	Right-Edge Line
Barrier Separated, Non-Reversible	A single, solid, normal, yellow line	A single, solid, normal, white line
Barrier Separated, Reversible	A single, solid, normal, white line	A single, solid, normal, white line
Concurrent Flow—Left Side	A single, solid, normal, yellow line	• A double, solid, wide, white line where crossing is prohibited • A single, solid, wide, white line where crossing is discouraged • A single, broken, wide, white line where crossing is permitted
Concurrent Flow—Right Side	• A double, solid, wide, white line where crossing is prohibited • A single, solid, wide, white line where crossing is discouraged • A single, broken, wide, white line where crossing is permitted • A single dotted, wide, white line where crossing is permitted for any vehicle to perform a right-turn maneuver	A single, solid, normal, white line

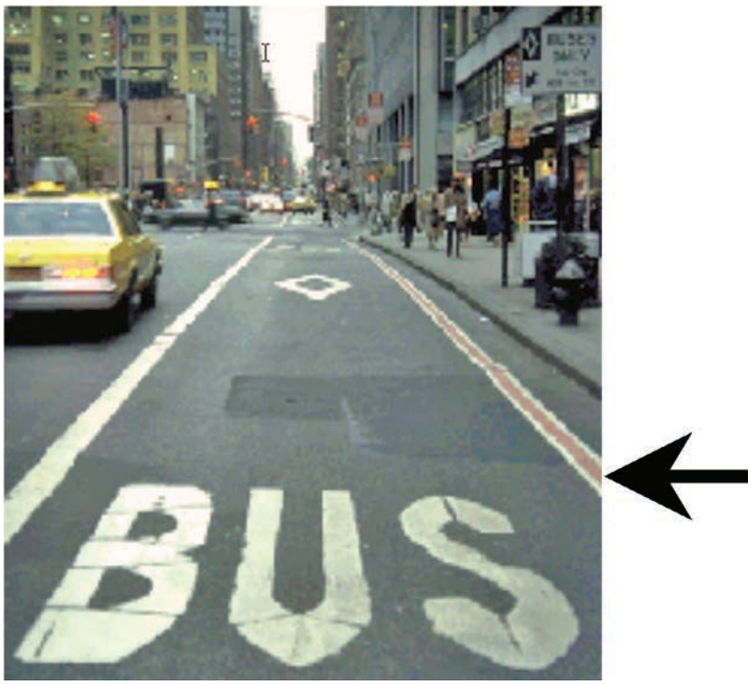


Figure 5-48. Red Curb Line for Bus Lane, New York

5.5.7 Spot Treatments

Bus-Only Links

There may be occasions where authorized buses can avoid out-of-way travel by using a short bus-only link road. The design of the link should follow normal practice, and signing should be clear in designating that the road segment is for use by authorized vehicles only.

If the link has a high risk of being used by unauthorized vehicles, several options are available:

- Increase the size and amount of static signing;
- Provide traffic signal control or physically gate the roadway—the gate may be opened either by bus-mounted transponder, driver swipe card, in-pavement detector loop, or similar remote actuation; and
- Use automated electronic enforcement by pole-mounted camera, activated by an approaching vehicle.

Queue Jumps

Bus queue jumps can be provided where a recurring queue of general traffic affects the speed or reliability of bus travel. Examples include ferry terminals, toll plazas, stadium entry/exit points, and construction zones. The queue jump normally takes the form of an appropriately signed dedicated lane. The key to the effectiveness of the queue jump is the speed, ease, and comfort of the bus re-entry into the general-purpose lane. (See discussion under traffic engineering treatments.)

Bus-Only Turns/Turn Lanes

Effective yet low-cost bus priority measures can sometimes be implemented by providing bus-only turn lanes or by exempting buses from turn prohibitions at intersections. These strategies are suitable for corridors where the bus volume does not justify a bus lane, and where they can be implemented without significantly affecting the general traffic flow. Figure 5-49 shows examples of bus-only turn lanes. Adequate physical provisions should be made for the allowed bus movement. Sustained and effective enforcement is essential. Examples of exemptions from turn prohibitions include:

- "Right Lane Must Turn Right"/"Buses Excepted;" and
- "Turns Prohibited 7:00 a.m.–9:00 a.m."/"Buses Excepted."

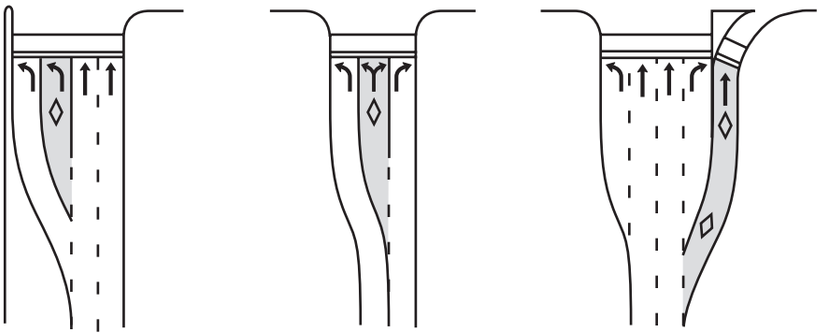


Figure 5-49. Examples of Bus-Only Turn Lanes

Right-Turn Provisions/Separate Lane for Right Turns

Conflicts inherent in sharing the curb lane by buses and right-turning vehicles make it desirable (physical and operational conditions permitting) to provide a separate right-turn lane for right-turning vehicles, thereby allowing buses an unimpeded approach to the intersection.

Allowing vehicles to turn right from the rightmost general purpose through lane (i.e., the second lane) is *not* recommended, unless it is performed on a protected phase and the turning vehicles can queue without disrupting the flow of through traffic. In practice, this approach is rarely used due to the safety concerns related to vehicles crossing the bus lane. It is common, however, for motorists to make such an unsafe turn from the second lane where the curb lane is designated for bus use. They may feel uneasy using the bus lane approaching the intersection or they may be bypassing a bus at a near-side stop. Signing, pavement marking, and driver education should be used to clearly direct turning motorists as to the appropriate course of action.

The more common—and preferred—approach is to provide a separate right-turn lane to the right of the bus lane. The length of the lane should be adequate to store the maximum queue to avoid spill back into the bus lane. A break in the pavement marking, supplemented by advance guide signs, should be provided to direct turning vehicles safely across the bus lane and into the turn lane.

The effect of a separate right-turn lane can also be achieved by operating buses in interior bus lanes.

Advance Stop Bar for Bus Left Turns

In some situations, a high volume of buses must make a left turn at a signalized intersection. It is usually difficult to make this turn safely and efficiently from a right curb bus stop before the intersection. If the bus must weave from a right curb stop across a busy multi-lane arterial to a left turn lane, the bus stop must be set so far back from the intersection that passengers transferring to or from a bus route on the cross street have a long and inconvenient walk. Furthermore, the weaving movement can be difficult for the bus operator and disruptive to the flow of through traffic. It is not always possible to avoid that situation by rerouting buses or by shifting the bus stop to the far side of the cross street (after the left turn).

An effective solution can be the provision of a signal and stop bar in advance of the intersection to allow the bus to move across the arterial and make the left turn freely and with minimum disruption to through traffic (see Figure 5-50).

The stop bar should be located back from the intersection stop line and at the head of the relocated bus stop or bus bay. The advance signal to bring through vehicles to a stop should be triggered (activated) by either the bus moving forward over an in-pavement detection loop or by another electronic means (e.g., bus-mounted transponder, side-mounted radar beam, or similar). The trigger should be located just downstream of the relocated bus stop. The bus should move clear of the bus stop to avoid the risk of a following bus not being able to access the stop while the turning bus awaits its go-ahead. The signal would operate for the few seconds required by the bus and revert to green until a red light for through traffic is triggered by the next bus.

The signal should be coordinated with the left-turn signal at the nearby intersection to let the bus move freely through the intersection after receiving the advance green. To minimize the risk of motorists "jumping the light," a transit-only signal head should be used to allow the bus to move ahead while other vehicles remain stopped (e.g., a two-phase signal showing a vertical white bar on a black background rather

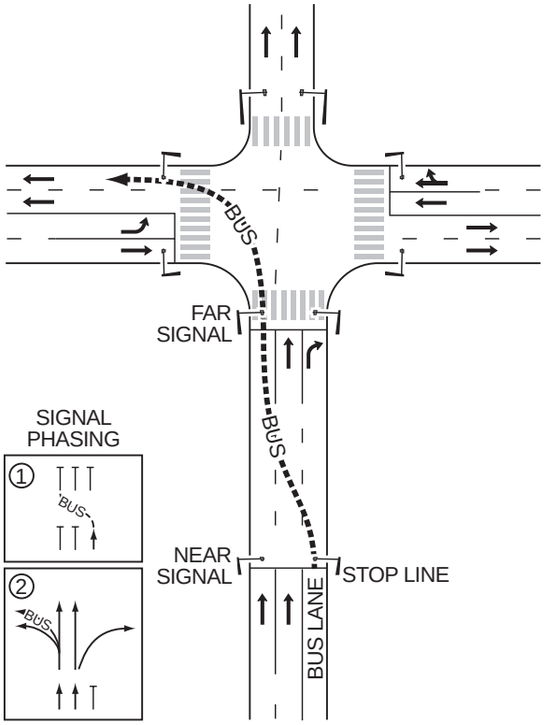


Figure 5-50. Advance Signal and Stop Bar for Bus Left Turns from Right-Lane Bus Stop

than a conventional three-head, green-amber-red signal). It should be located within the bus driver's field of view and not necessarily visible to all motorists.

The advance signal should be far enough back from the cross-street signal that motorists do not confuse the two. It may be signed as such.

The warrant for implementing an advance signal should be based on a benefit–cost analysis, considering transit delays, safety issues, passenger transfer impacts, and net delay to general traffic.

5.6 MEDIAN BUSWAYS AND STREETS

5.6.1 Cross-Sections and Design Considerations Between Intersections

General Considerations

Median transit operations provide conflict-free movement for express and limited-stop buses and allow buses to avoid the demands by other vehicles for use of the right curb lane. A median facility is likely to be developed as a high-standard dedicated busway, which implies use by frequent buses adhering to a high average speed, with limited on-line stops. Depending on the local environment, median arterial busways may be supplemented by local frequent-stop bus service operating in the right lanes in general traffic. Median arterial busways have been widely used throughout Central and South America. The Bogotá, Curitiba, and Quito systems are recognized for their innovative designs, such as high-platform stations, off-vehicle fare collection, and specially designed vehicles.

Figure 5-51. Median Busway, Vancouver

A busway in the center of Canal Street, New Orleans, replaced street cars circa 1960, and operated until street cars were re-introduced about 40 years later. A median arterial busway operates along Vancouver's 98-B-Line bus rapid transit lane (see Figure 5-51) connecting Richmond, British Columbia, to downtown Vancouver.

Busways normally require wide streets. A least two lanes should be available for general traffic on each side of the busway, although where space is restricted, one-through lane and parking lane may be provided each way. The busway and station areas add the equivalent width of three to four lanes. The busway lanes, station areas, and physical separations generally require at least 22 to 24 m (74 to 80 ft) minimum curb-to-curb.

The bus-lane width should be at least 3.3 m (11 ft), preferably 3.6 m (12 ft), even if this requires reallocating width from other lanes. The width of the curb lane could be reduced to 3.0 m (10 ft) as a first step, or less if it serves as a parkway lane.

Separation from General Traffic

Physically separated median arterial busways represent the ultimate level of on-street at-grade BRT in terms of sophistication, cost, capability, and identity. Placing reserved bus lanes in a segregated median operation essentially creates a "bus-only road" in the center of an arterial, similar to many arterial streetcar operations. The physical separation from general traffic significantly enhances transit operations by eliminating potential conflicts with vehicles. Breaks in the physical barrier are provided at signalized intersections and designated crossings. Provision for left-turning general traffic must be limited to signalized intersection locations where protected signal phases are provided.

There are a number of ways to provide physical separation of general traffic lanes and the busway, ranging from rumble strips to roll-over curbs, medians, and concrete barriers. The type of separation provided can affect the cost of the facility, width of the median facility, the ability to conduct maintenance operations, opportunities for pedestrian refuge, and the overall effectiveness of the facility.

Table 5-12. Relative Effectiveness of Various Busway Separations

Effectiveness	Type
Least	Lane Markings
	Rumble Strip
	Half-Globe
	Raised Roll-over Curb
	Flexible Post
	Concrete Barrier
Most	Raised Median Island

A rollover curb is well suited to allowing buses to bypass a disabled bus, or to allow the bus lane to be used as a detour under police direction. However, since the curb does not preclude entry by non-transit vehicles, it poses some risk of inappropriate or inadvertent use.

A raised median prevents general traffic from crossing or entering the busway, but it also forms a barrier for emergency vehicles, potentially increasing their response time. In areas with high pedestrian traffic and infrequent signalized crossings, the potential exists for numerous mid-block crossings of the roadway by pedestrians. Although this is not generally legal, it does occur and could be accommodated by implementing a raised median barrier that pedestrians may view as a refuge within the roadway. Crosswalks should be provided where mid-block crossing is to be accommodated. In situations where snow clearance is required, half-globe barriers or flexible posts may interfere with plowing operations.

All potential impacts should be considered in selecting a barrier treatment for median busways. Although one alternative may provide the greatest benefit to transit operations, the secondary impacts may prove substantial and justify the use of a different barrier. Table 5-12 ranks the various types of separation methods in order of increasing effectiveness.

5.6.2 Intersection Treatments

Accommodating Left Turns for General Traffic

The location of the bus facility in the arterial median will interfere with left turns from adjacent general purpose lanes. Unless there is no demand for left turns or left turns are banned, allowance must be made for left-turning vehicles. Streetcar operations face the same issues. The general practice is to minimize the number of left-turn locations by consolidating the turning movements at selected signal-controlled cross streets. There are several ways to provide for left turns:

- Where the blocks are small enough and suited to the operation (for example, in a CBD), left turns can be accomplished by a series of "around the block" right turns.
- A protected left-turn slot (signalized or unsignalized) can be provided in the middle of the bus facility. The left-turning vehicles can weave across the bus lane through a designated break in the lane into the slot. This requires widening the busway to provide a turn lane at the center of the busway. It normally precludes locating stations where left turns are permitted.
- A left-turn lane can be inserted between the bus lane and the leftmost through lane. In such a case, left turns can occur only on a protected signal phase. This is a common treatment. Stations can be placed

on the far side of intersections (and left turns on the near side), thereby accommodating both in the same envelope.

- Left-turning vehicles can be directed to a queue in the right-curb lane, out of the path of through traffic. They then may turn left across all traffic on a protected signal phase. Although this arrangement is uncommon in North America, it is normal practice in Melbourne, Australia, to avoid conflicts between turning vehicles and the extensive streetcar operation.
- Where transit volumes, left-turn volumes, and arterial street volumes are low, and where there is a near-side bus stop where buses will be stopping anyway, the bus lane can be shared with left-turning vehicle storage. Careful operational analysis is required to ensure that the delay to through buses is kept to an acceptable level. This strategy may be applicable during off-peak periods only, as the risk (and consequences) of delay will be magnified during peak periods when transit volumes increase, left-turn volumes increase, and fewer left-turn gaps are available. It is generally undesirable.

If a substantial number of buses turn left at a particular location (for example, into an off-street transit hub), a separate bus-only left-turn lane may be provided in the median. A bus-only left-turn lane normally should not be located at the same intersection as a protected general purpose left turn.

Accommodating Right Turns for Buses

Where a substantial number of buses turn right from the busway, a right-turn lane within the busway with an activated right turn phase should be provided. A right-turn lane within the busway is desirable so that the stopped buses do not block through bus movements. For situations involving low volumes of right-turning buses, the bus can leave the median facility before going to the intersection—possibly at an upstream intersection with an advance green transit phase—and operate in mixed-traffic lanes, accomplishing the right turn from the curb lane. In both cases, the busway through movements can occur at the same time.

Signal Phasing

Turning movements from the median should be conducted on protected signal phases. Through movements, however, can be accommodated either on protected transit signal phases or with through phases for general traffic.

In situations where a median bus facility displaces a high number of mid-block left-turns to signalized intersections, it may be beneficial to introduce U-turn capabilities for general traffic to minimize traffic infiltration into neighborhoods abutting the arterial road. These can be accommodated from the general traffic left-turn lane with a protected phase at signalized intersections.

Signal phasing should be tailored to each situation, accounting for the configuration of the intersection, existing traffic and volumes, signal, control systems, pedestrian requirements, and forecast busway use. The public agencies involved should determine the importance to be placed on transit operations and how to balance signal phasing/timing to achieve optimum operation of the intersection.

5.6.3 Bus Stops and Stations

Median arterial busways mainly serve express, limited stop, or BRT services with wide stop spacing. When passengers must be served with frequent stops, local bus services should continue to operate in

mixed flow using conventional stops to achieve good transit operating speeds while maintaining passenger accessibility at key locations. Median busway on-line stops should be spaced, generally, at intervals no less than 600 m (2,000 ft).

At major intersections or transfer points where express buses serve large numbers of boarding, alighting or transferring passengers, bus stops should be provided either on in-street island platforms or on a central (median) island platform. The side platform is common although center island platforms are sometimes used, in both cases, passenger platform width should be at least 3.0 m (10 ft) wide to meet ADA requirements.

In-street island platforms are described under Design Considerations in Section 5.5.4. Use of a single central island platform either requires buses to operate in a concurrent flow situation to cross over the median to a contraflow position or, to avoid the crossover, exclusive use of buses with double-sided doors. Contraflow operations can use a shared center-island platform with no additional provisions.

The crossover allows use of a center island platform by conventional buses but may require special measures to minimize the risk of a head-on collision and to prevent its use by unauthorized vehicles. The arrangement puts buses in a contraflow position at the platform, and designers should consider the degree of separation provided between stopped buses and oncoming traffic, such as whether paint, delineators, raised curbing, or a physical barrier is appropriate.

The single center island provides the benefits of consolidating passenger shelter, information, and access in one place. It can be wider and more comfortable than a typical in-street island, and is buffered somewhat from the flow of traffic. It provides greater opportunity than narrow in-street platforms to contribute to the streetscape and to function as a landmark or gateway. However, space limitations may preclude providing left-turn lanes for general traffic.

Side-platform stations can be placed on the far side using the same space used by a near-side, left-turn lane.

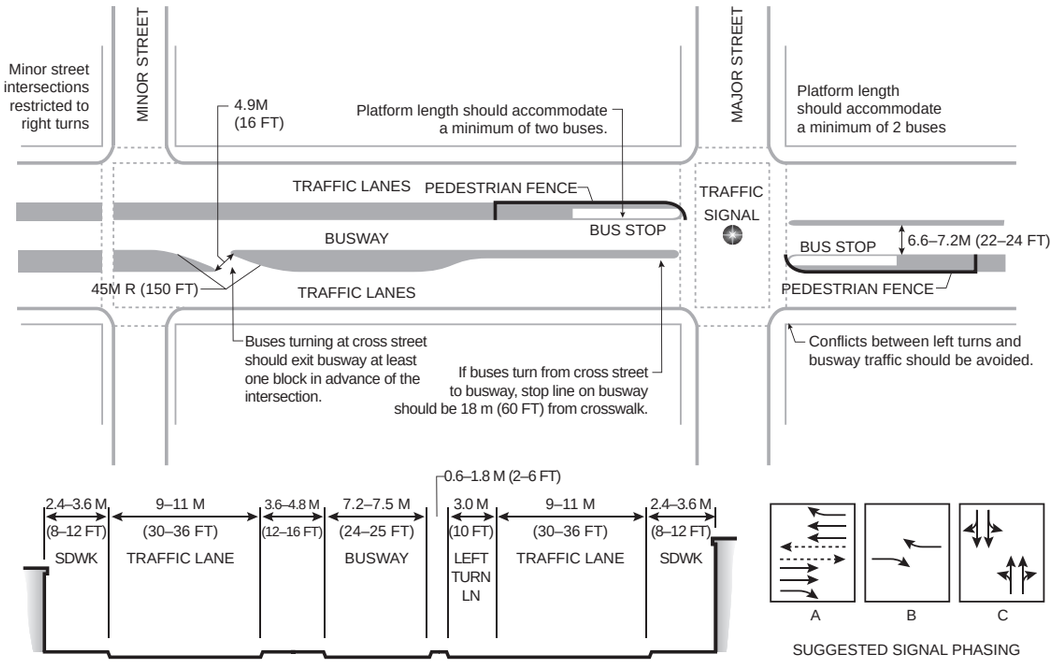
Figures 5-52, 5-53, and 5-54 illustrate designs for side-platform stations.

- Figure 5-54 shows a conceptual design for a wide boulevard-type roadway that provides far-side stops and a near-side signal combined with left-turn lanes. Buses move on the same traffic signal phase as the through movement, left turns move on a protected phase *after* the through movement to minimize same-direction, bus/car crashes.
- Figure 5-55 shows a more likely application for a 24-to-25 m (80-to-84 ft) curb width. The barriers between the busway and bus lanes provide space for signing or delineators.

Where rights-of-way and roadway widths are limited, it may be necessary to prohibit left turns at intersections where stations are provided. This makes it possible to fit busways within a curb-to-curb width of 21 to 23 m (70 to 75 ft). However, it is necessary to transition the busway alignment at locations where turn lanes or stations are located. Figure 5-56 illustrates this method.

5.6.4 Bus Streets

Bus streets provide cost-effective means of improved downtown distribution for express and local buses. They may be desired where high bus volumes traverse narrow streets, or as part of downtown revitalization



Source: Adapted from Levinson et al., 1975.

Figure 5-52. Median Arterial Busway Design for a Wide Roadway (*13*)

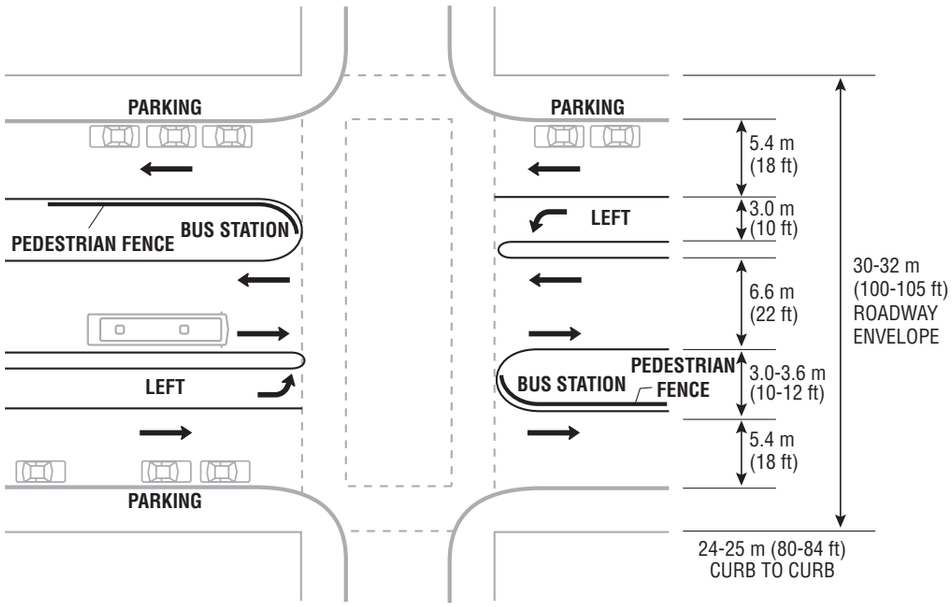


Figure 5-53. Typical Median Arterial Busway Design with Left Turns

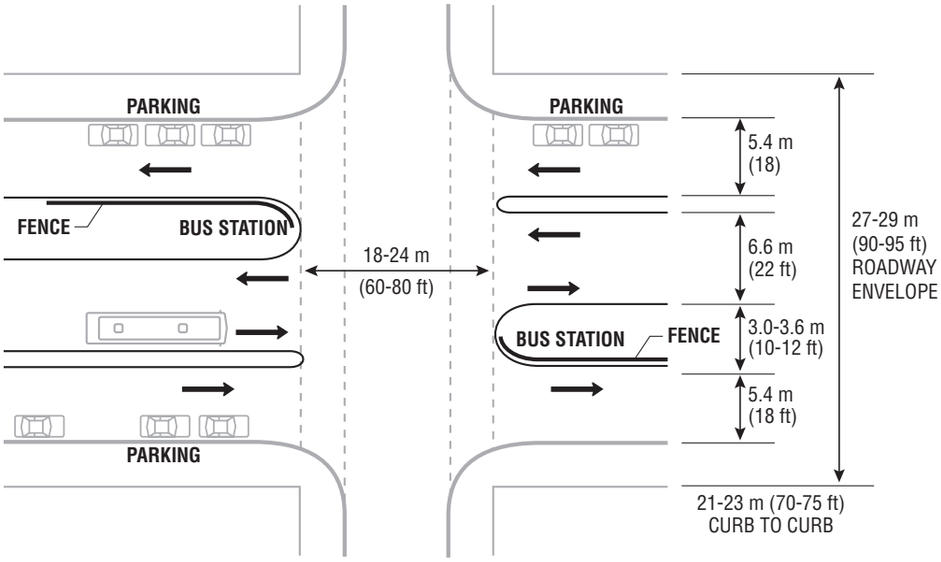
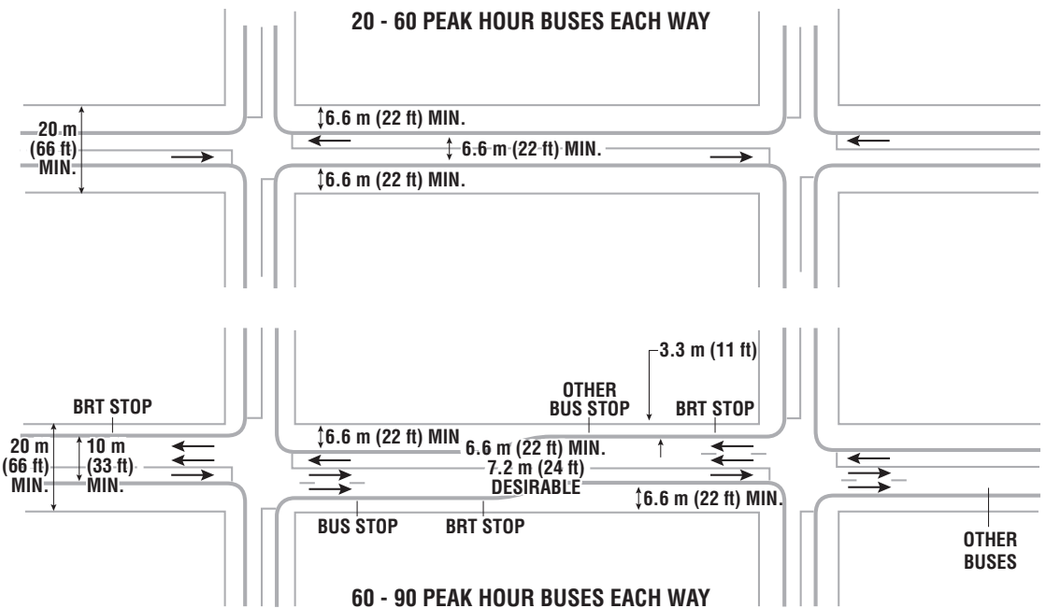


Figure 5-54. Typical Median Arterial Busway Design Without Left Turns



NOT TO SCALE

Note: If over 90 buses each way, dual-width lanes may be desirable.

Figure 5-55. Typical Bus Street Designs (*13*)

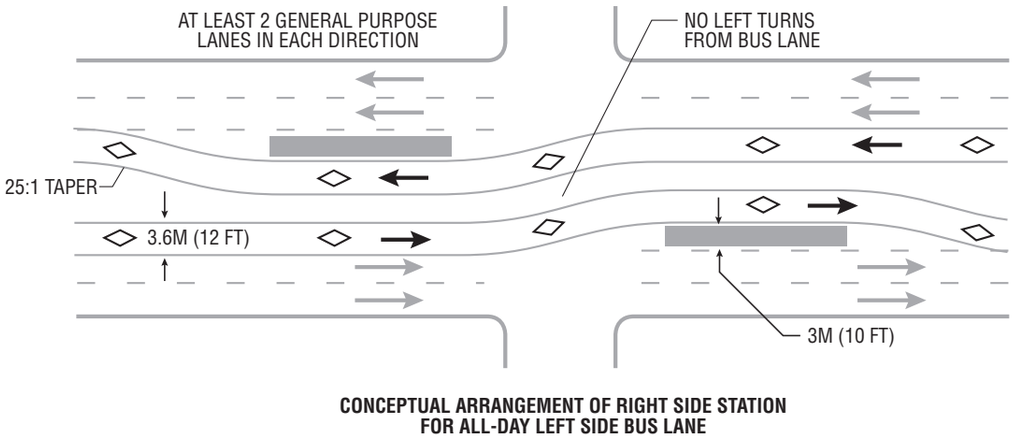


Figure 5-56. Conceptual Arrangement of Right-Side Station for All-Day, Left Bus Lane

proposals. They may include the last block of an arterial street, a dead-end street at the end of several bus routes; a "bus loop" necessary to change directions at major bus terminals; service on downtown bus malls; and bus circulation through vehicle-free bus zones.

Reserving streets for buses can improve service speeds, reliability, and identity. Designers should select streets that provide maximum advantage without hindering other traffic and access to adjacent areas.

Generally, bus streets should serve major concentrations of bus flow resulting from the convergence of individual lines in a single street. They should penetrate the heart of the city center to provide direct access to major activities. They should represent logical extensions of running ways on radial arterials or freeways, and they should be closely tied to pedestrian mall development, where applicable.

Reasons

Bus streets benefit busway operations by fully separating bus and vehicle traffic. They clearly identify transit routes, and they are easy to enforce. They enable buses to pick-up and drop-off passengers at places where shopping and business activities use buses. They are found in several U.S. cities, and they are extensively used throughout Western Europe.

Bus streets provide more walking space for pedestrians and waiting space at bus stops. They can be part of an overall downtown improvement program activity and investment. But as their use by buses increase, they become less attractive for pedestrians and vice versa. They are a compromise between giving buses unhindered passage to carry passengers close to their desired destination, and providing freedom of pedestrian movement.

Design Consideration

Bus streets should incorporate curb loading zones for off-peak service vehicles when service cannot be provided from intersecting streets or off-street. Where other options are not practical, pick-ups and deliveries can be permitted from the bus streets when the bus traffic is low (i.e., night hours).

Access to parking garages may require vehicle use for short discontinuous sections of a street. Such an arrangement is incorporated in Portland, Oregon's, dual-lanes one-way 5th and 6th Avenue bus streets, where cars must turn off the bus street at the first cross street after leaving the parking garage.

Bus streets should provide passing opportunities around stopped buses where bus flow is heavy, the distances involved are more than 0.3 km (0.5 mi), and many other buses use the street (Figure 5-55). Stopping positions for express and local service buses should be separated.

Bus streets usually are two-way roads 6.6 to 7.2 m (22 to 24 ft) wide. This configuration is adequate where there are fewer than 50 peak-hour buses one way. When there are more than 60 buses per hour, it is desirable to provide passing opportunities at stops. Bus stops may be near side or far side and generally should accommodate at least three buses. Where blocks are closely spaced, the stops may extend an entire block. For very heavy bus volumes (more than 90 buses per hour each way), dual lanes are desirable in each direction. Specific designs can include bus pull-outs, central medians at key points, widened sidewalks, connections to skywalks, information systems, and passenger amenities depending upon specific community needs. Where the length of a bus street is less than three or four blocks, it may be feasible to eliminate cross vehicular movements if their traffic flows are low.

Designers must ensure that other traffic is not unduly impacted, and that parallel routes are available for displaced traffic.

5.7 ENFORCEMENT

Effective enforcement of bus lanes, bus streets, and on-street busways is necessary. Some types of treatment, such as contraflow bus lanes and median arterial busways, are self-enforcing. Others, however, such as curb-side bus lanes and queue jumps, require constant surveillance.

5.7.1 Provisions for Bus Lane Enforcement

Extended Bus Turnout

A bus bay turnout lengthened to provide a clear space for enforcement activities—either for staging a police vehicle or for holding violators—without disrupting the flow of buses in the lane or at the bus stop. The space may also be used for a transit inspector's vehicle. A 15.2-m (50-ft) extension with a 1:1 return taper provides an adequate area for this purpose. The location and frequency of enforcement turnouts will depend on property availability, enforcement needs, and frequency and impact of lane violation. Consultation with the local police officials is required to determine whether, where, and how to use extended bus turnouts.

Signing

Posting a roadside or overhead sign to emphasize the consequences of bus lane violation can be useful both as a deterrent and as an education device. A precedent has been set by the effectiveness of posting fine rates for violation of freeway HOV lanes in California in reducing violations. Ottawa, Canada, posts the bus lane fine rate on overhead signs. The practice has been reported to be effective in reducing violations and maintaining public respect for the facilities. For the posting of fines to be effective, however, the fine level must be substantial enough to act as a deterrent and actual police enforcement must occur regularly.

Bus-Mounted Camera

The use of bus-mounted video or still cameras for detecting bus lane violators has been established in London, England, and elsewhere. It requires no special infrastructure or design features on the bus lane.

Bus-Lane Camera

Vehicle detectors can be used for enforcement if the detectors are equipped to read bus-mounted identification tags. Selected detectors can be linked to a pole-mounted camera such that any vehicle passing over the detector without registering a tag can trigger the camera to photograph the vehicle and license plate, much the same way that red-light cameras operate. The appropriate legal framework to allow citation by mail must be in place for remote or electronic enforcement of bus lanes.

5.7.2 Fines and Programs

Active enforcement programs are essential. Because it is not practical to enforce all curb lanes that have priority treatment with equal vigor, enforcement programs must be targeted. Enforcement programs should include both fines and towing of disabled vehicles. Fines for illegal use of bus lanes and curb parking violations within the lane should be high (e.g., $50 to $250 per violation).

Each community should establish an aggressive towing program that removes illegally parked vehicles along bus lanes and bus routes. Specific strategies are best implemented when involving the respective merchants and adjacent property owners, police, traffic court, judges, and district attorneys. Posting of fines on signs can help reduce violations.

Design Characteristics

The bus lane should be at least 3.3 m (11 ft) wide, preferably 3.6 m (12 ft), even if it requires some reallocation of width from other lanes. The lanes in the center of the roadway eliminate the passenger loading, curb access, service and right-turn problems associated with normal flow curb bus lanes.

Stations can be provided in the center island if buses also have left-side doors. Conventional right-side stations can be provided where the lanes operate at all times by shifting the lanes into the median and providing 3.0-m (10-ft) platforms. Stations should be staggered to minimize the required envelope (Figure 5-56).

Intersection Treatments

Left turns from all-day bus lanes should be eliminated wherever possible, but left-turning vehicles on the arterial may be allowed to cross the reserved lane and turn from median left-turn bays. Under no circumstances should left-turning vehicles (cars or buses) block the reserved lane to through-traffic. Left-turn movements should be controlled by a protected signal phase. A solid white line should separate the bus lane from the adjacent lane. The line can be broken about 150 to 200 m (500 to 660 ft) in advance of intersections. Special signing and pavement markings should guide vehicles turning left into the arterial from crossing streets into the general traffic lane rather than the bus lanes.

When the left-side bus lanes operate during peak hours, only signs should clearly indicate where vehicles can enter or cross the lane to make turns.

In both cases, bus-lane signs should be provided, along with “diamond” pavement markings.

Right turns at intersections from the left-side reserved bus lane should be prohibited. If a high volume of right-turning buses uses the lane, an advance signal or dedicated right-turn bay may be desirable. The bus driver could activate the right-turn phase from a dashboard switch or by more sophisticated means (such as a vehicle recognition system with a route identifier programmed to trigger a right-turn phase) to limit signal interruption to only those times when it will be used by a right-turning bus.

5.8 ITS DESIGN DETAILS

Intelligent Transportation Systems (ITS) use technologies based on information processing, communications, and electronics to address transportation problems. Examples include traffic signal priority systems, real-time passenger information systems, bus stop security systems, and automated toll collection. This section addresses design of:

- Traffic signal systems for transit priority;
- Real-time/automated passenger information systems; and
- Other ITS provisions related to transit operations on streets.

5.8.1 Traffic Signal Operations for Transit Priority

Granting priority treatment to buses at signalized intersections can contribute significantly to operating buses in a fast, reliable manner on arterial streets. This can be accomplished as a stand-alone initiative (independent of whether there are bus lanes) or as an integral part of a BRT scheme for the corridor. Signal priority is in widespread usage worldwide and has proven to be cost-effective in many situations (*14*).

It is important to recognize that schedule adherence is more significant to transit operations than absolute transit priority. It is as important that buses do not arrive at a stop earlier than their scheduled time as it is to speed up delayed buses. The last thing a passenger wants to see upon arriving early at a stop is to see the scheduled bus pulling away.

The transit operator's objective is to minimize the proportion of off-schedule buses—typically defined as vehicles that are more than one minute ahead of schedule or more than three to five minutes behind schedule. If all buses can operate within that schedule window consistently under various conditions, then the transit agency will be able to reduce the amount of slack in the system, and thus improve operational efficiency.

The road authority responsible for overall intersection operations wants traffic delay for non-buses to be minimized, signal progression to be maintained, pedestrian needs to be unaffected, and cross street delays to be minimized. Although dedicating part of the traffic signal cycle to bus operations may delay some intersection users, an effective signal priority system may reduce overall intersection delay on a per-person basis. Operating a signal on the basis of least total person delay is a fundamental change from traditional signal operations that focus on minimizing total vehicle delay.

Principles

The basic principle of Transit Signal Priority (TSP) is that a bus is automatically detected on the approach to a signalized intersection and the signal timing and phasing is adjusted to provide the bus with clear passage through the intersection. This may save the bus up to one minute or more of waiting at a red light. When transit priority is implemented along a lengthy corridor, the cumulative travel time savings can be significant, even more so when considered on a per-passenger basis.

Passive signal priority can benefit transit service, requires no equipment, and operates regardless of the presence or absence of a transit vehicle.

Active signal priority can take several forms:

- **Early Green—**When a bus is detected approaching on a red phase, the cross-street's green phase(s) is truncated.
- **Extend Green Phase—**When the bus is approaching on a green phase, the phase extends until the bus passes through.
- **Insert Special Bus Phase—**When a bus is at the intersection, a bus-only or turn phase allows the bus to move while other vehicles are stopped.
- **Re-order Phases to Favor the Bus Route—**Shift, for example, a lagging left-turn phase to a leading left to accommodate a waiting or approaching bus.

Adaptive/real-time TSP strategies make use of constantly updated traffic and transit information to implement priority (using any or all of the above tools) within an overall integrated system. Older signal controllers, such as NEMA and Type 170, do not have the computing power to operate adaptive/real time TSP systems. Advanced transportation controllers such as Type 2070 are required.

After the bus has cleared the intersection, the signal controller transitions back to "normal" operation. The transition or recovery period may take one or two cycles, and if another bus arrives during the transition period, the signal may struggle to get back to "normal." This can have adverse consequences, particularly for cross-street traffic and signal progression on the major street. Often systems are designed to ignore requests for priority during recovery periods.

TSP differs from signal pre-emption. TSP modifies the signal timing to accommodate transit, while pre-emption (e.g., for an emergency vehicle or a train crossing) interrupts the signal cycle; after the interruption, the cycle returns to the normal signal timing plan. Transit priority does not normally involve pre-emption.

Operational Strategies to Maximize Benefits

The benefits of signal priority are maximized if one or two high-frequency bus routes serve the corridor, so that benefits are accrued over the length of the corridor and by many transit vehicles and passengers. The goal is to achieve travel-time savings and consistency of travel time to achieve or maintain a high quality of service, thus reducing the number of buses required to provide the service.

The combination of route length and service frequency should be analyzed to determine the travel-time savings needed to eliminate one bus from the route. A 48 km (30 mi) round trip operating on five-minute headways at an average speed of 20 km/h (12.4 mph), for example, requires 30 buses in service; that number could be reduced to 29 if the average speed could be increased to 21 km/h (13 mph) by way of a five-minute average round trip travel-time reduction. The buses "saved" may be reallocated to other routes or used to increase service on the priority route. Ranking all city corridors by this measure can help prioritize application of signal priority systems.

The annualized savings in terms of fleet size and operating cost can be substantial. However, if the priority corridor serves only parts of routes or forms a small part of a lengthy route, it is less able to generate substantial savings. For example, if five-minute headways are provided by six different routes, each operating at 30-minute headways, it will be more difficult to gain enough travel time to save a bus on any individual route.

The improvement in reliability and schedule adherence is a strong attractor of new transit trips. Signal priority can thus increase ridership while simultaneously reducing operating costs. The key variables are the capital and operating costs of the priority system, and the degree of impact on other vehicles using or crossing the corridor.

Only buses that are behind schedule or on schedule generally benefit from signal priority; buses that are ahead of schedule should not be granted priority. Furthermore, on a route where buses can maintain their scheduled service, or in a corridor where service is so frequent that being "on schedule" is irrelevant to the passenger, signal priority is not likely to bring substantial benefits to the service. TSP is most suited to congested arterials with long signal cycles serving several bus routes at moderate-to-low headways. In oversaturated situations, the effectiveness of priority treatments becomes more problematic as buses will be caught in queues unless a fully dedicated lane is provided. In oversaturated conditions, recovery or the clearing of queues may not occur and penalties to other roadway users may be deemed excessive.

Signal priority works well with far-side bus stops, by allowing buses to approach the stop uninterrupted. It is more challenging to implement for near-side stops because the dwell time must be considered after a bus has been detected, and it may be difficult to trigger the priority phase after a bus is ready to leave the stop. On-board driver actuation (by a dashboard button) may be needed, but driver intervention is not preferred.

A version of TSP is to provide a bus-only signal that is activated in the same manner but showing red to all approaches for a brief period during which the bus passes through the intersection or makes a turn across the intersection. This is more common in the case of median transit lanes and busways (particularly when buses need to turn from the median) or where buses must turn left from a right curb lane. Table 5-13 summarizes expected benefits from TSP application.

Application Guidelines

Traffic signal priorities are desirable when the following conditions apply:

- Person-minutes saved by bus and vehicle passengers along the bus route exceed the person-minutes lost by side-street vehicle drivers and passengers;
- Side-street green time can be reduced and still provide adequate clearance times for pedestrians crossing the artery; and
- Increased queues on side streets are manageable.

Table 5-13. Transit Signal Priority Benefits

Greater Benefits Achieved	Lesser Benefit Achieved
Buses behind or on schedule	Buses ahead of schedule
Congested corridors	Oversaturated corridors
Variety of bus routes with moderate to lengthy headways	High frequency service where "on schedule" is irrelevant to passenger
High transit ridership corridors where overall person travel times savings can be increased (even when vehicle travel times may increase).	Low level of transit ridership unless done while aiming for significant ridership increase
Far-side stops	Near-side stops

Suggested guidelines are:

- The traffic-signal cycle may extend or advance the green time. The additional green time should be available only to buses running late.
- Priorities should not be given in two successive cycles.
- Approaching bus flow volumes in any direction should not exceed 20 to 30 buses per hour.

The Los Angeles Metro Rapid Transit Priority System along Wilshire and Ventura Boulevards follows these guidelines. Late buses are given preference at most (but not all) signalized intersections. The green time may be advanced up to 10 percent of the cycle length when a late bus approaches the system. Buses had been delayed at more than 211 intersections. Buses reportedly have saved about 12 seconds per km (20 seconds per mile).

Design Approach

The transit agency and the signal operator should define the functional parameters for the TSP (*14*). This agreement shall consider:

- Roadway geometry and traffic volumes;
- Traffic improvements at cross streets to increase capacity;
- Traffic signal hardware and software (capability of existing equipment; specifications for future equipment);
- Traffic signal operation;
- Overall person delay;
- Pedestrian needs;
- Coordination with other signals/signal progression;
- Emergency pre-emption systems, if present; and
- Traffic agency signal operation policy and practices.

Meanwhile, the transit operator will need to consider TSP needs in the context of:

- Bus service and operations (express/local bus mix, left-/right-turn requirements, etc.);
- Bus stop location;
- Compatibility with existing transit hardware and software (ability to communicate between the bus and the roadside);
- Transit agency operating policies, practices, and standards (e.g., on-time performance criteria); and
- Coordination with other transit priority measures such as bus lanes.

Transit Vehicle Detection System

Transit vehicles may be detected in four ways:

- Driver activated "alerts";
- Point detectors;
- Area detectors; and
- Zone detectors.

Experience has shown that driver-activated systems are ineffective in practice, because drivers tend to leave the "priority request" call on rather than use it only when necessary, resulting in inefficient signal operations and an overall increases in delay. For the other applications, various commercial technologies are readily available. These technologies include in-pavement magnetic induction loops, side-fired radar, optical strobe, ultrasonic, microwave, global positioning satellite (GPS), and photographic devices.

Detection may be "dumb" and simply look for a vehicle body type or axle spacing that represents a bus, or it may be a "smart" system that registers a bus's identification tag and checks whether it is in service and ahead of or behind schedule. Where the signal is also set up for emergency vehicle priority treatment, emergency vehicle requirements will override any transit priority processes.

In a "point" application (e.g., a loop located upstream of the traffic signal), costs are minimized but information on bus speed and location is limited and the signal priority system must guess somewhat, either based on recent/previous bus travel patterns or on a pre-set basis. A set of multiple detectors helps overcome that problem, but that may not be a concern if transit operations are fairly consistent on the intersection approach.

An "area" detection system (e.g., using GPS to continuously track buses through the roadway network) provides better information to the TSP system. A "zone" system is a smaller version of an area system, limited to the immediate approaches of the intersection. When the system detects a bus in the zone, the system alerts the controller that priority is needed.

In any case, the detection system must be tied to a bus schedule/route database to determine if a particular bus is delayed and actually requires signal priority. The detection location must be far enough in advance of the signal that there is time to adjust the signal timing and allow the bus to approach the site without dropping speed and momentum. This distance will vary according to the operational speed of the road and the technology used.

After a bus is detected, the bus detection system must communicate its presence to the traffic signal controller. If the signal is in a green phase, the controller typically will extend the green phase until the bus has passed. If the signal is showing red, the controller will truncate the green on the cross street and move to green on the bus approach as early as possible. Changes are limited by minimum length for cross-street pedestrian phases. The cycle length may change or selected phases skipped to accommodate the bus.

If the signal is located within a progression, any transit priority changes should be designed carefully so as to maintain the integrity of the progression. In a heavily traveled corridor, the benefits of maintaining signal progression for general traffic may outweigh the benefits of providing signal priority to buses that require independent operations.

It is desirable to install an "exit detector" immediately downstream of the signal, to register the passage of the bus and advise the signal controller to return to "normal" phasing. This minimizes the delay imposed on other traffic. If there is no downstream detector, the signal controller should be set to return to "normal" phasing after a specified period.

Communications System

Communications links between the various TSP elements are important but may have little impact on infrastructure design. If the communications system is based on radio or wireless links between the bus and the control center or between the bus and the traffic signal controller, the issue is more one of system design and electronics, rather than roadside infrastructure. If the communications system is based on vehicle detection by in-pavement loops or pole-mounted beacons, then the specific design parameters for those technologies must be followed.

5.8.2 Passenger Information Systems

If buses are tracked throughout the roadway network, or even on just one street/route, the information provided to the bus operator also can be provided to passengers at stops. Information also can be disseminated on the Internet, monitors in retail/office centers, closed-circuit television, telephone, cellular (mobile) telephone, pagers, and other media (Figure 5-57).

The most common means of providing real-time passenger information at bus stops is to display the anticipated time of arrival of the next bus on an illuminated sign. Signs may be elaborate or simple, and can use various technologies. For a stop hosting just one route, a simple "countdown to next bus" display is adequate. For a stop used by several express and local routes, a multi-line display may be needed that details the next buses on each route and their destinations, or the order of arrival of the next four or five buses. A multi-line display is particularly useful if buses tend to arrive in platoons or so closely spaced that passengers have a hard time picking up the route numbers of following buses. If passengers know the order of arrival, they can move to an appropriate spot on the platform to board.

Figure 5-57. Real-Time Passenger Information

If the display is a countdown type (e.g., "Next Bus in 4 Minutes"), there is no need for a clock display as well. If the display shows the anticipated arrival time (e.g., "Route 324 at 4:42"), a system-synchronized clock display should also be provided.

Passenger information displays can take many forms. They can be attached to a pole at the stop, incorporated within a bus shelter, or be in a stand-alone kiosk. The displays should, if possible, be located upstream of and oriented toward the stop, so that a waiting passenger can view the sign at the same time as seeing an approaching bus.

Designers should carefully consider the requirements of visually impaired customers. The size, color, shape, and brightness of the information displays in all weather conditions (especially full sunlight) should be tested in the field before committing to a particular style or technology. Designers should consider providing a supplementary audio loop for visually impaired users. See "Building a True Community-Final Report" (1) for more information.

Another key consideration is protection from vandalism. Displays should be enclosed in a protective case and located high, out of direct reach of vandals. Designers may consider monitoring and videotaping signs and stops by closed-circuit television.

Signs may be turned off overnight, or left on with a note to the effect that "Service Resumes at _ a.m."

The decision to use the signs and to prioritize their implementation at locations within a system or corridor will be a function of:

- Passenger needs;
- Funding;
- Cost of acquisition and maintenance; and
- Transit system image-building/marketing.

Real-time passenger information systems can be implemented in coordination with other system upgrades (for example, new bus shelters or a BRT system). Opportunities may exist for cost reduction or quality improvement through commercial sponsorship, particularly with respect to using the signs for advertising messages. If the signs are used for marketing, the primacy of their intended use for transit information must not be affected.

5.8.3 Other ITS Provisions

A wide range of ITS applications emerging in the United States and abroad could influence roadside design for bus operations. Some applications are safety-oriented, such as warning of an approaching bus at a stop or busway intersection or guidance technologies built into a busway to improve vehicle and driver safety. Most such provisions are targeted at system performance, efficiency, and communication between end-users and operations management. For example, a growing number of regions are adopting "511" information systems which provide a wealth of information in real-time for a wide range of transit and transportation services. ITS provisions can promote improved service reliability, schedule adherence, dispatcher monitoring, and enhanced passenger communication.

Some accepted communication strategies that provide schedule updates at transit stations, for example, are now being delivered externally to personal computers, cell phones, personal digital assistance devices, and other devices targed at helping potential and regular transit patrons make informed choices about specific transit services and their status. The specific application is likely to require some form of in-vehicle and roadside detection or monitoring capability which, in turn, can be relayed through various channels. Technology is changing rapidly, so no specific guidance is presented in this chapter. The goals and objectives of each project and service likely will dictate the unique ITS needs and provisions for a specific street or roadway along a corridor.

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6 Light Rail and Streetcar Facilities on Streets and Highways

In This Chapter:

This section provides guidelines for light rail and streetcar facilities within arterials and highways. It covers operations in mixed traffic, in reserved lanes, and in segregated rights-of-way, and for shared-bus facilities in separate transit alignments. The guidelines cover roadway design, traffic controls, and stations. More thorough guidelines for the design of light rail transit (LRT) facilities in segregated rights-of-way can be found in various references (*4, 9*).

- Light rail transit is defined as a metropolitan railway system characterized by its ability to operate single cars or short trains along shared rights-of-way at ground level, on aerial structures, in subways or in streets, and to board and discharge passengers at track or floor level. Light rail transit may operate on aerial structures, in subways or in streets with exclusive rights-of-way (*3*).

- A streetcar is an electrically powered rail car that typically runs singly in mixed traffic on a track in city streets. Its motive power is derived through a trolley (a wheeled device running on top of wires). In earlier times, "streetcars" referred to vehicles in local urban service, and "trolleys" reached points beyond the built-up area. In Europe, the streetcar is referred to as a tram.

6.1 HISTORICAL CONTEXT

Light rail transit is reminiscent of the streetcar and interurban electrical railway systems that operated throughout the United States and Canada a century ago. Most of these systems were replaced by buses before World War II. Early examples of light rail lines include the Boston Green Line system, the Shaker Heights Rapid Transit, and the Pittsburgh South Hills Rail Lines that

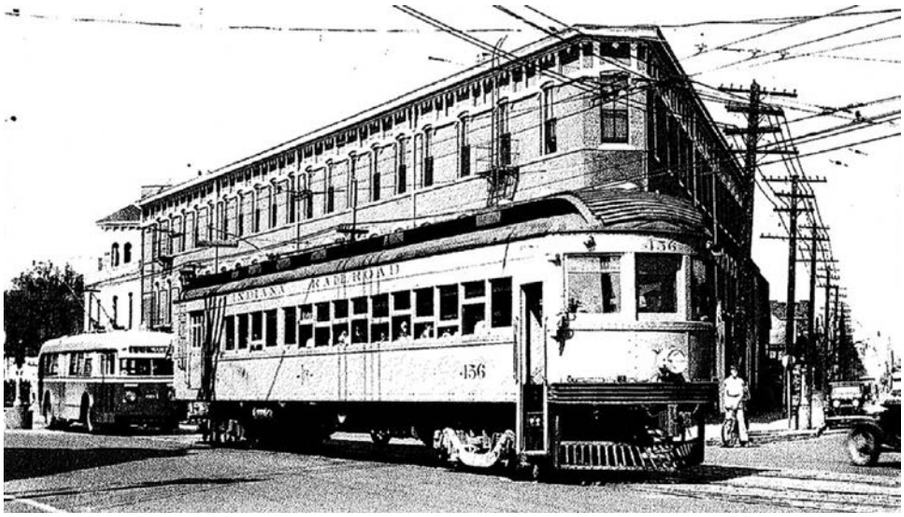


Figure 6-1. Street Running Interurban, Indiana (1937) (*2*)

are still in service. Many other cities once had some form of light rail lines—Los Angeles, Milwaukee, St. Louis, Portland, and Seattle are just a few examples. Most cities with populations of over 100,000 in the 1920s had streetcars in operation.

The interurban electric railways extended beyond cities into outlying communities. Most accommodated passengers with little freight service. Some were streetcar extensions into the surrounding countryside; others were built to railroad standards and became high-density, high-speed carriers. Most remaining systems, however, served commuter markets by 1940.

Most interurban railroads and streetcar lines operated on city streets, but a few had electrical or subway access into the city center. They operated in the centers of streets within built-up areas (Figure 6-1) and along the side of the road in outlying areas (Figure 6-2).

Rail cars mainly ran in the center of streets in mixed traffic. In Philadelphia, for example, a single track was placed in the center of 7.8-m (26-ft) streets, and in Chicago the tracks were placed in streets as narrow

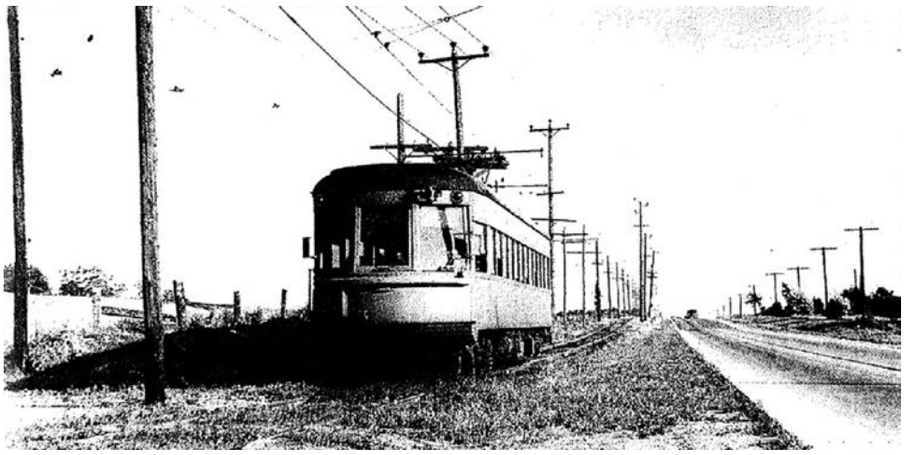


Figure 6-2. Side Running Streetcar, Indiana (1930s) (*2*)

Figure 6-3. Street Loading 63rd Street, Chicago, Illinois (1951) (*5*)

as 11.4 m (38 ft). Streetcars turning right or left conflicted with automobiles, since there was no special traffic signal protection.

Passengers boarded cars from the street (Figure 6-3). Safety islands were provided where space permitted (Figure 6-4). Today, a few large cities where long-established streetcar lines run still have this type

Figure 6-4. Safety Island, Irving Park Road, Chicago, Illinois (1944) (*5*)

of passenger boarding, but these conditions are not possible to implement today. The growth in motor vehicle traffic since the end of World War II has made it increasingly difficult for the streetcars to operate reliably in mixed traffic and for passengers to board and alight from streetcars. Moreover, since 1990, at least 2.4 m (8 ft) clear width must be provided to meet ADA requirements.

Most street railway lines were converted to bus operations by the 1960s. Many of the remaining lines in Boston, Cleveland, Newark, Philadelphia, and San Francisco had, or were given, exclusive right-of-way access to central business districts.

LRT has become increasingly popular as a practical application of rail transit. LRT is a hybrid of streetcars and interurbans that can operate on a various rights-of-way, from on-street to grade-separated. It may use shared or exclusive rights-of-way, high- or low-platform loading, and multi-train or single cars. As with the interurbans before them, LRT vehicles can mix local service in city centers with express service to peripheral communities and suburban activity centers. Several light rail lines operate over former interurban rights-of-way (*12*).

Many of the LRT systems developed since 1970 have parts in a city center operating in-street, parts operating in semi-exclusive rights-of-way, and exclusive parts built in abandoned or underused freight railroad rights-of-way. In exclusive operation, conflicts with pedestrians and other motor vehicles are less frequent, average speeds can be higher, and station spacing tends to be more distant. LRT can also operate in a semi-exclusive environment within the median of a wide roadway. In this configuration, cross-streets present potential conflicts. In this setting, there are no other motor vehicles in the LRT vehicle's path between cross-streets, thus enabling faster and safer transit operations.

Light rail lines typically use articulated vehicles powered from an overhead catenary. Power is drawn from the overhead electric lines by a trolley or pantograph. LRT has "light" capacity and vehicle weight, as compared to heavy rail rapid transit which functions entirely in exclusive guideway.

6.2 GENERAL PLANNING AND DESIGN GUIDELINES

Planning and design guidelines for light rail transit on streets and highways generally are similar to those for buses. Facilities for each can be located curbside or in the center of streets. Vehicles can operate in mixed traffic, reserved lanes, or segregated running ways. Far-side stops are required for transit signal priority, as they enable station platforms and left-turning motor vehicles to share the same roadway envelope. Station platform berths are governed by ADA requirements.

Since LRT operates on fixed track, maneuverability is inhibited around motor vehicles blocking the track. LRT vehicles are usually longer than buses and run in two- or four-car train-sets. They require larger clearances and turning radii, longer stopping distances, and they must be protected from conflicting traffic whenever they turn right or left. Their proper design and accommodation can enable a community to use its limited street space for several modes and purposes, and to improve the travel options of its citizens.

This section outlines general planning and design considerations and guidelines. It identifies the need and applicability of LRT, and describes the various types of LRT running ways. It presents vehicle dimensions and geometric design requirements, basic track design considerations, and ITS applications.

6.2.1 Need and Justification for Light Rail Transit

The decision to develop LRT should be based on an objective analysis of present and future needs and should be a cooperative effort of public agencies and the impacted community. (See Chapter 2 for further details on the decision-making process.) From a federal perspective, the decision should be based on an objective assessment of various public transportation alternatives in terms of their benefits, costs, and impacts. The goal is to achieve cost-effective public transportation investments in terms of costs, ridership, travel-time savings, and land enhancement or development benefits.

City Size and Structure

The desirability of LRT should reflect each community's physical features, settlement patterns, activity concentrations, traffic conditions, and growth prospects. The specific factors that influence a community's suitability for LRT service include:

- **Physical Features**—Hills, bodies of water, and other barriers tend to concentrate travel and are conducive to rail transit development.
- **Population Size**—The urbanized area population should be sufficient to generate enough ridership to make rail transit service practical. Generally, there should be at least 750,000 to 1,000,000 residents.
- **Population Density**—Density should be sufficiently high to generate enough trips to make service practical. A minimum central city density of at least 2,000 people per square kilometer (5,000 people per square mile) is desirable.
- **Employment Density**—The clustering of employment should provide a concentration of destination points. Central business district employment generally should exceed 75,000.
- **Topography**—The terrain should not be excessively difficult for rail vehicles (slippage of wheels on steep grades).
- **Traffic Congestion**—Communities with extensive traffic congestion in freeways and arterial streets are good candidates for LRT development.
- **Available Rights-of-Way**—Wide streets, underutilized or abandoned railroad corridors, freeway rights-of-way, and similar opportunities for placing track are desirable.
- **Economic/Land Development Opportunities**—The ability to cluster development along potential LRT corridors or to use LRT as a means of catalyzing transit-oriented development and redevelopment should be considered.
- **Civic Image and Community Attitudes**—The community's desire to search for and advance transportation infrastructure and to support LRT is desirable. The ability and willingness to commit needed financial resources is essential.
- **Land Use/Future Growth**—LRT aids in attempting to minimize urban sprawl and to encourage mixed-use and transit-oriented development and redevelopment.
- **Modal Shift**—LRT may encourage modal shift by encouraging motorists to use transit.
- **Air Quality**—LRT may decrease or slow an increase in vehicle miles traveled and have a positive effect on air quality.

The ideal situation for LRT development is a corridor, at least 10 km (6.25 mi) long, that has strong destination points and trip attractions at both ends (e.g., a CBD, a shopping center, a medical complex, a university campus, a research or office park, an airport, a sports or recreation facility). The corridor needs comparable, if less intensive, development activities along the route. This corridor should encompass residential areas with at least moderately high density (preferably 100 dwelling units per hectare or 40 units per acre) within walking distance of the service line (0.5 km [0.3 mi]). Beyond the central spine, residential districts of medium density (10 dwelling units per hectare, or 4 per acre) could connect to the LRT by convenient feeder bus services. The CBD should anchor the line. The route should use exclusive running ways to the maximum extent possible.

In very large urban areas with rail rapid transit lines, LRT can serve as feeder to the rail lines (e.g., the Mattapan–Ashmont Line in Boston) or be developed in complementary corridors (e.g., Baltimore).

Streetcar lines—sometimes heritage or tourist-oriented lines—may be appropriate in smaller communities, especially where developments are not concentrated along a corridor, or as an urban circulator.

Future Conversion of Busway to LRT

Operating experience in Ottawa, Pittsburgh, and elsewhere in North America has demonstrated that busways and LRT have similar passenger-carrying capacity. The decision on what is appropriate in a particular corridor depends on corridor land use, right-of-way availability, system connectivity, and costs. In some cases, corridor/land uses can be expected to change and conversion to LRT may be appropriate.

Provision for future LRT conversion should be limited to the main (or trunk line) bus operation right-of-way only and should not apply to busway ramps or connecting roads. On the busway proper, the accommodation of a possible future LRT conversion should reflect the use of current light rail vehicle (LRV) standards for:

- Vertical clearances/track integration;
- Right-of-way geometry and grades;
- Structural loading;
- Drainage along trunk lines; and
- Utility accommodations (power and communications conduit).

These standards should apply to busways only where the marginal cost to meet them is possibly less than about five percent of the future cost to replace the item in question.

Where the additional cost to meet the LRT standard can easily be deferred, this should be considered; for example, a retaining wall required only to accommodate the horizontal or vertical alignment of LRT as compared to a busway. Similarly, where the additional bridge loading of an LRT vehicle can be accommodated by the future addition of beams or cross-bracing, this approach should be taken. In such instances, the addition of phantom details to a limited number of drawings to show how the conversion can be accommodated is desirable. Another element normally considered is barrier walls on bridges. Accommodations for future catenary support foundations may not be feasible, but ground returns for electrolysis cable connections should be provided at all underground utility crossings.

Table 6-1. LRT Alignment Classifications (*23*)

Class	Category	Description of Access Control
Exclusive	Type A	Fully grade-separated or at-grade without crossings
Semi-Exclusive	Type B-1	Separate right-of-way (with at-grade street crossings)
	Type B-2	Shared right-of-way protected by barrier curbs and fences
	Type B-3	Shared right-of-way protected by barrier curbs
	Type B-4	Shared right-of-way protected by mountable curbs, striping, and/or lane designation
	Type B-5	LRT/pedestrian mall adjacent to a parallel roadway
Non-Exclusive	Type C-1	Mixed traffic operation
	Type C-2	Transit mall (may share space with transit buses)
	Type C-3	LRT/pedestrian mall

Station buildings and platforms are sometimes regarded as replaceable within the long-range timeframe in question and should not be designed for LRT operation.

During any conversion from busway to LRT operation, diversions onto adjacent local streets of one or both directions of bus travel, while a likely option, is not desirable. Protection of the extra right-of-way to allow for detours for this purpose is not cost-effective. If early conversion is expected, integration of tracks or track forms in concrete may be desirable. Perth, Australia, is undergoing such a conversion in one transit corridor.

6.2.2 Types of LRT Services and Facilities

The general classification of LRT alignments by degrees of right-of-way exclusivity is summarized in Table 6-1. Right-of-way exclusivity is divided into three classes:

- **Class A**—exclusive (rail has own right-of-way with no conflicts);
- **Class B**—semi-exclusive (rail shares part of right-of-way, such as at-grade street crossings or mixed bus-train use separated from general traffic by curb, fence, striping, or lane designation);
- **Class C**—non-exclusive (rail shares right-of-way with mixed traffic, cross-traffic, and/or pedestrian traffic).

This chapter focuses on the rail operating in street and highway rights-of-way. Therefore, Type A projects are not covered in this guide.

The following discussion describes the range of situations where light rail facilities can be integrated into street and highway environments. The range both illustrates and builds on the alignment classification shown in Table 6-1. LRT can operate within arterial streets in lanes shared with other traffic, in reserved lanes, or in separated channels (within the center of a road or elevated). LRT can operate in reserved or shared space on arterials, operation within a freeway right-of-way, or within a separate facility. Its configuration may be single or double track.

Single-Track and Double-Track Operations

Double-track designs provide the greatest operational flexibility and should be planned for or provided whenever possible. Single-track operations may be considered in the following circumstances:

- For short sections that involve bridges or tunnels;
- As a means of reducing initial construction costs, with provisions for adding a second track when more funds become available and ridership warrants more frequent service and requires more frequent and flexible operations; or
- As a split pair of tracks on parallel one-way streets.

Where street space is limited, activity centers are slightly dispersed, or as street patterns suggest, a pair of LRT tracks traveling in opposite directions may be split along parallel one-way streets. A "split pair" will have one direction of travel on one street and the other direction on an adjacent parallel street. This alignment works for narrower streets, allowing larger pedestrian service areas and better integration into existing traffic patterns. Splitting the alignment can minimize the loss of directional street capacity. However, costs are usually higher for split pairs. Figure 6-5 illustrates an example of split pairs in San Jose.

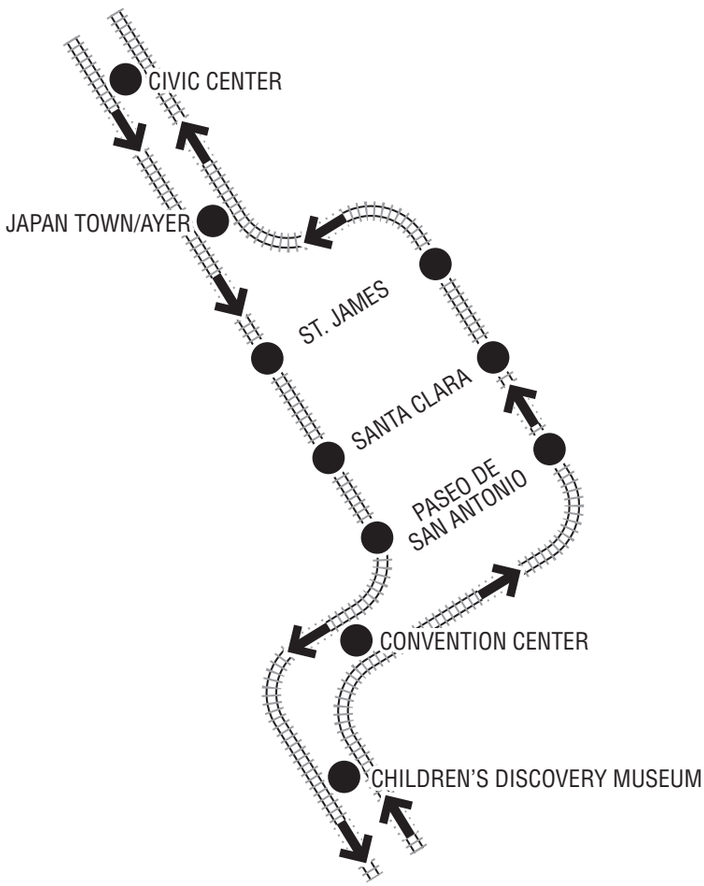


Figure 6-5. Portion of LRT Map Illustrating Split Track Pair, San Jose, California (*18*)

Figure 6-6. Streetcar in Mixed-Flow Conditions, Portland, Oregon (*21*)

Arterial Operations in Mixed Traffic (Type C-1)

Arterial streets and roads often penetrate commercial and retail land uses that generate travel demands for both motor vehicles and transit. Where space is limited for a separate transit channel, or it is not practical to provide a reserved lane, some LRT and many streetcars operate in mixed traffic lanes. LRT can operate in mixed flow on local streets, narrow major streets of older CBDs or even along major arterials. Examples include Boston, New Orleans, Portland, San Francisco, and Toronto (Figures 6-6 and 6-7). In this arrangement, little traffic capacity is lost (the equivalent of the space used by each LRT vehicle) while transit is able to serve busy markets. LRT offer improved passenger comfort (smoother acceleration/deceleration, and less lateral shifting) and has environmental advantages (quiet and clean electric operation) over bus transit. LRTs may also have speed advantages over the general traffic flow.

LRT/Bus Lanes (Types C-1/C-2)

Many municipalities have established bus lanes that operate during peak periods or throughout the day. The lanes are striped for identification, but rarely have physical separation (barrier curbs or fences) from general-purpose lanes. When LRT is introduced, tracks frequently are located in the lanes. Combined LRT/bus lanes are found in Calgary and Pittsburgh.

Restricted lanes eliminate some, but not all, motor vehicle-LRT conflicts. Conflicts remain at intersections, at places where general traffic must turn across the LRT/bus lane, and when transit vehicles must turn across general-purpose lanes to enter or exit the lane. LRT/bus lanes have nonexclusive alignment.

LRT Malls (Type C-3)

LRT malls are designed as largely exclusive streets for transit vehicles and pedestrians with shops on each side and often with decorative plantings, benches, and pedestrian amenities. They may accommodate

Figure 6-7. Streetcar in Median Lane of a Boulevard, New Orleans, Louisiana (*21*)

buses and LRVs or just the LRTs (Figure 6-8). LRT malls can have a semi-exclusive alignment (Type B-5) in which one lane of traffic and a separate LRT track share the street with pedestrians, or non-exclusive alignment (Type C-2) in which LRT vehicles share the mall with buses. There are examples of LRT malls in Buffalo, San Diego, Sacramento, Portland, and Houston.

LRT malls still require some level of motor vehicle access to service adjacent busineses (i.e., deliveries, trash removal, etc.), but access is usually restricted to specific hours and accommodated in the facility design so these motor vehicles do not block transit operations. Also, conflicts between the LRT and other vehicles remain at intersections.

Arterial Operations in Separate Channel (Type B)

The operating advantages of providing separate channels or semi-exclusive right-of-way sometimes with little or no physical separation is encouraged. Even historic streetcar lines were built alongside major arterials in separate rights-of-way, affected at cross-streets by turning movements from the arterial, or in the median of arterials which affects all cross-streets. Modern LRT systems follow the same practice where possible. Arterials are attractive routes for transit because of the many land use activities lining them. With a semi-exclusive alignment, transit can be introduced into a busy street with minimal traffic impacts. Examples may be found in Baltimore (Figure 6-9), Dallas, New Orleans, and Houston.

Tunnel Portals

Rail and road tunnels are built in hilly terrain to avoid steep grades and/or to provide shortcuts to suburban activity centers and residential areas. Urban rail street tunnels are found in Los Angeles, Pittsburgh, and San Francisco. Light rail transit tunnels (and tunnel portals) are found in Boston, Portland, Dallas, Los Angeles, Pittsburgh, Baltimore, and San Francisco. San Francisco's initial LRT tunnels were built in the early part of the 20th Century to connect the CBD with outlying residential areas.

Figure 6-8. LRT Downtown Mall, Houston, Texas (*14*)

Figure 6-9. LRT Arterial Operations in Separate Channel, Baltimore, Maryland (*18*)

Figure 6-10. Muni Metro Twin Peaks Tunnel Portal, San Francisco, California (*21*)

Tunnel portals are the link with the adjacent street environment. Careful design and effective integration into the adjacent street environment are needed to minimize potential pedestrian and vehicle confusion.

The portal locations, sometimes governed by grade and geologic factors, and the treatment of sidewalks and traffic lanes in their environs are important design elements. Greater exclusivity of LRT alignments is desirable near portals to limit conflicts.

Figure 6-10 shows the tunnel portal for the N-Judah Line in San Francisco. A station just beyond the portal turns the transition area from tunnel to city street operation.

Elevated LRT (Type A)

Elevated LRT lines provide exclusive conflict-free operations. LRT and elevated structures can be provided to cross busy streets (Figure 6-11), or to penetrate the urban core where space is at a premium. There are elevated LRT sections in several locations, including Baltimore, Boston, Los Angeles, St. Louis, and San Diego. LRT load and dynamic characteristics more closely resemble vehicular and bus traffic. Therefore, the structural requirement and cost ranges for an LRT elevated structure are comparable to those of highway overpasses, although cathodic protection may be needed in the structural design to address overhead catenaries and supports.

Reserved Space in Freeway Rights-of-Way (Type A)

Most rail transit facilities within freeway rights-of-way accommodate heavy rail rapid transit (e.g., Washington, DC, Chicago). Examples of LRT lines in the median or along freeways can be found in Los Angeles, Portland, San Jose, and San Francisco. These running ways enable LRVs to attain high speeds, especially where stations are widely spaced. Passengers can reach stations by bus or from park-and-ride lots, but direct pedestrian access from surrounding areas is usually difficult unless the LRT alignment is located on the side of the freeway. LRT alignments in these settings must be fully barrier-separated as Figure 6-12 shows.

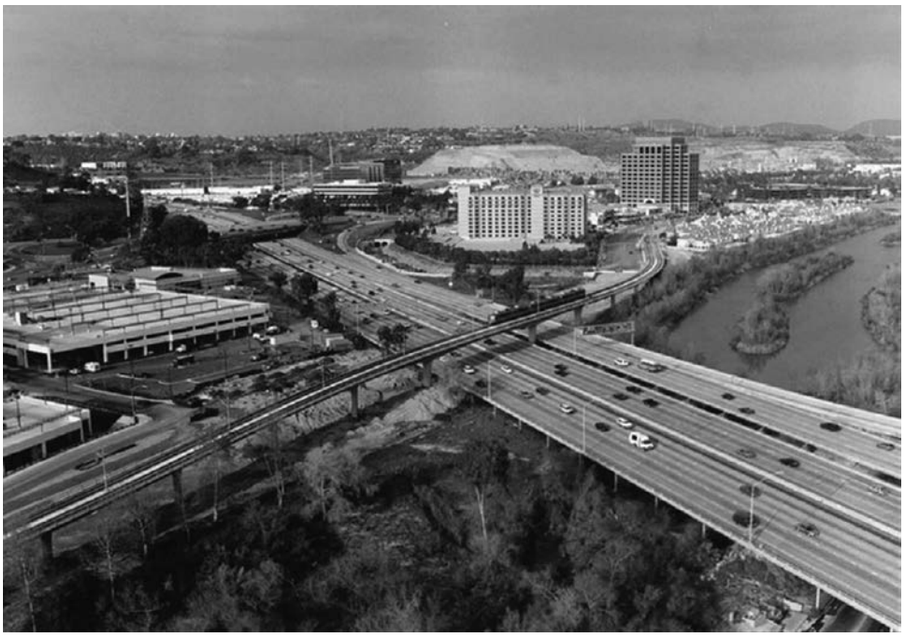


Figure 6-11. San Diego Trolley Green Line Over State Route 163

Shared Bus-Rail Facilities in Exclusive Rights-of-Way (Type A)

In cities with high-transit ridership and high-service frequency, transit-only facilities can be provided for the exclusive use of buses and LRT. These may take the form of facilities on separate rights-of-way (similar to the MT Washington Tunnel in Pittsburgh) or within freeway rights-of-way. These facilities can move large numbers of people efficiently and quickly without being delayed by general traffic. Only

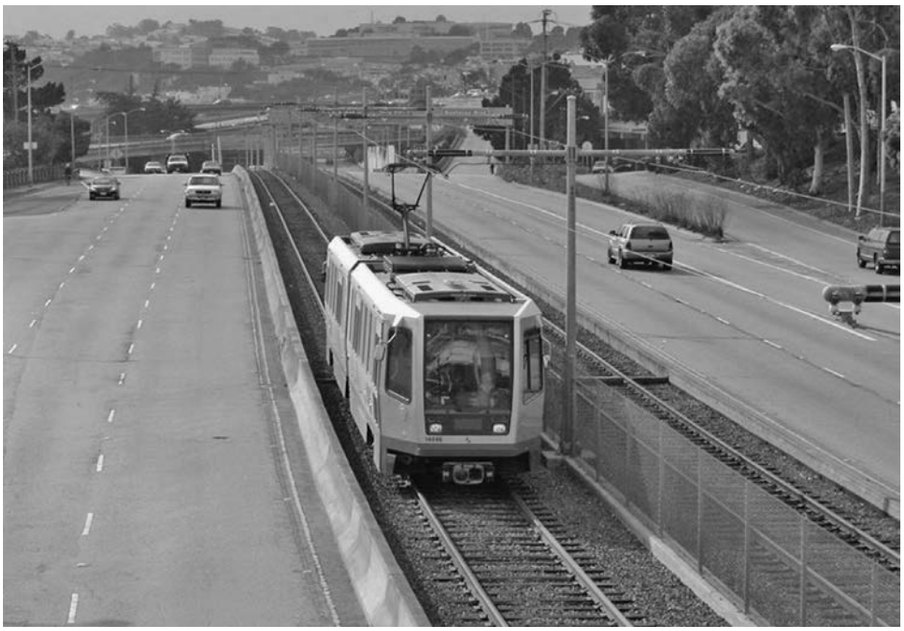


Figure 6-12. LRT within Freeway Right-of-Way, San Francisco, California (*21*)

Table 6-2. Light Rail Transit Vehicles Design Parameters (*11*)

Parameter	Range
Gauge (inside spacing between rails)	1 m (3 ft, 4 in.) 1.435 m (4 ft, 8.5 in.) standard railroad gauge 1.63 m (5 ft, 4.5 in.)
Vertical clearance (top of rail to bottom of wire)	3.5 to 5.5 m (11 ft, 6 in. to 18 ft, 5 in.)
Lane width (dependent on the model of the car; no more than 3.6 m [12 ft])	Width of the car plus 0.3 m (1 ft) clearance on each side (the clearance may be reduced to 0.15 m [0.5 ft] within controlled spaces) Width of reserve for two tracks: 5.8 to 10 m (19 to 33 ft)
Distance between centerlines of track	About 3.6 m (12 ft)
Maximum gradient	6 percent
Minimum horizontal radius	11 m (36 ft) for streetcars 12 m (40 ft) for very slow speeds
Minimum width of platform	3 m (10 ft)
Height of platform	Low: 25 to 35 cm (10 to 14 in.) High: 90 to 99 cm (36 to 39 in.)
Power supply	600 V, 700 V, 750 V DC Diesel engine

vehicle performance, station spacing, and dwell times limit operational speeds. Designs can provide passing lanes for buses at stations.

Facilities within freeway rights-of-way should be physically separated from other traffic lanes by barrier curbs or fences.

6.2.3 Light Rail Transit Design Dimensions

Exact dimensions and geometric design requirements for LRT will depend upon the specific vehicles used. Table 6-2 provides the most common parameters and ranges (*11*).

The width of a two-track channel for LRT, considering the dynamic envelope, is 6.6 to 7.2 m (22 to 24 ft). However, where catenary (or trolley wire) supports are located between the tracks, a 7.8 m (26 ft) envelope is desired (see Chapter 3).

6.2.4 Intelligent Transportation Systems for LRT

Infrastructure requirements should consider ITS in facility design, and covers a broad range of diverse technologies. Essentially ITS uses improved computer and communications technologies to make transit systems work better, saving customers time, improving operational efficiencies, and enhancing safety. The variety of applications is growing, and the infrastructure required to support the technology is changing.

ITS-related systems include track detection, train signal control, train communications systems, traffic signal system interconnections and priority measures, passenger information displays, security surveillance, and call boxes. An overview of the more common applications follows.

Figure 6-13. Passenger Information Display (*18*)

- **Train Communication.** Improved communication systems have several LRT applications. New systems can enable immediate communication between the vehicle operator and passengers (when the operator is in an enclosed cabin) to improve customer service and passenger security. Rapid communications between the operator and the dispatcher can improve system operations. Many systems have elements of advanced communication systems (e.g., linear antennae along the alignment).

- **Track Detection/Signal Control.** Track detection systems are commonly used to activate crossing arms and flashing lights at railroad crossings. A newer application enables the local traffic signal control system to integrate LRT movements and activate signal controls when LRT vehicles or trains approach a signalized intersection.

- **Traffic Signal System Interconnections and Priority Measures.** Most traffic engineers are familiar with interconnected traffic signal systems that permit signals to be coordinated to facilitate traffic flow or respond to changes in traffic patterns associated with peak periods or special events. (This technology can be applied to LRT systems to enable them to communicate with the traffic signal system via track detection devices or radio communications). This is especially useful where an extra phase must be inserted when trains are present, or where transit priority policies are in place.

- **Passenger Information Displays.** Providing current information to passengers eases anxiety and makes using transit more predictable. Passenger information displays can include video or variable message signs at stations announcing the anticipated arrival time of the next train and/or its destination (if a station is served by more than one transit line). Figure 6-13 shows a variable message display. The displays can be used to inform the riding public of schedule changes, unusual delays, or emergency conditions. Passenger information displays on the vehicles can identify routes and announce pending stops (both visually and audibly). On-board systems can relieve the operator of making routine stop announcements while keeping customers informed.

- **Security and Surveillance/Call Boxes.** Many bus and rail transit systems now routinely install cameras on board vehicles, at stations, and at busy intersections to record accidents or security incidents. Cameras can be mounted on the front of vehicles to record the view of the operator in the event of an accident. Cameras at stations or stops can be used for active monitoring, especially during late hours. These may transmit data by telephone lines or radio to a central command center. Telephone call boxes can be installed at stations to enable riders to contact the command center in case of an emergency or security threat, and command center numbers can be posted for cell phone users.

6.2.5 Track Design Considerations

Streetcars and light rail transit vehicles collect power from an electrified overhead wire. The direct current travels to the motors (located under the vehicle chassis), where it is transformed into motive power. Because it is the nature of electrical current to complete a circuit, some electrical current leaves the vehicle by the metal wheels to the tracks trying to return to the source of the electricity fed through the overhead wires. Much of the stray current can be directed through the rails for a safe return into the system by properly insulated rail. Otherwise, some small amount of stray current will travel through groundwater into the surrounding area. The stray current can have a corrosive effect on metal objects near the tracks.

The most effective method to prevent the stray current from entering the ground is complete insulation of the tracks. There are several methods for insulating the tracks, including attaching a rubber "boot" around the bottom and sides of the rail when it is installed. Typically, the rubber-wrapped rail is embedded in concrete pavement surrounding each rail and the gauge area between the rails. As with any roadway pavement design, attention must be given to providing adequate foundation support for the slab of concrete and to the joint between the concrete part of the roadway and any asphalt part of the roadway.

The electrified overhead wire that powers the transit vehicles is supported by a physical system of foundations, vertical poles, insulators, brackets, cantilevers, and other assemblies and components. This system should support the contact wire in accordance with the requirement that the trolley pole and contact shoe (of a streetcar) or the pantograph and contact bar (of a LRV) maintain contact with the electrified wire during all operating and adverse climate conditions. This catenary support system must be insulated from the electric current and often includes a system of pulleys and counterweights at strategic locations to maintain a constant tension (and elevation) for the electrified wire. The catenary system can be simple where track is straight, but at points where track switches allow vehicles to turn and on curved portions of track, the support system can become quite complex. The proliferation of poles, guy wires, and overhead power lines can become an aesthetic issue and often nearby vegetation, especially mature trees, must be trimmed to avoid conflict. Where possible, the catenary system may be supported by anchoring into the façades of nearby buildings, but this approach can present legal and property rights issues.

Trolley wires are common for street-running LRT, especially in central areas. Catenaries generally are used for high-speed operations on exclusive rights-of-way.

The catenary supports and trolley poles may be located between tracks, alongside tracks in off-street operations, or curbside. Curbside poles/supports should be located about 1 m (3 ft) from the roadway curb, although closer spacing is sometimes used.

6.2.6 General Guidelines

The following general guidelines should be considered in designing LRT (or streetcar) operations into roadways.

General Alignment/ Trackway

- LRT lines should be direct, use high type rights-of-way, and minimize turns to the maximum extent possible.
- Lines should double track wherever they run on two-way streets. Double tracking provides better operations flexibility for high-frequency train service, and travel directions are clear to motorists.
- Single-track lines work well on one-way street pairs and require smaller street envelopes. They may operate concurrently with general traffic flow or in a segregated lane in the opposing direction.
- Sufficient crossovers between tracks are desirable to allow for operations when one track is blocked, or to accommodate short-turning trains. Where short-turn service is anticipated, a short section of third track would prove beneficial if space is available.

Running Ways

- Segregated LRT running ways are preferable to transit lanes of mixed traffic operations. They permit faster and more reliable service in street and highway environments. Separate running ways are obviously required alongside freeways.
- Segregated median LRT on arterial streets generally requires two adjacent lanes available for general traffic. This limits their application to wide six- and eight-lane arterials. Left turns, where permitted, should operate in a protected signal phase.
- Reserved LRT lanes, where provided, may operate on a 24-hour basis or during peak periods. They may be designed to accommodate just LRVs, or for simultaneous use by LRVs and buses.
- An LRT lane should be at least 3.3 m (11 ft), preferably 3.6 m (12 ft). However, where buses operate in the lanes, provisions must be made for buses to pass stationary trains. On segregated rights-of-way, passing lanes at stations are desirable if space permits. However, buses may have to move to adjacent lanes to pass stopped trains.
- LRT tracks can be placed in the center or roadways or along the curb.
- Curbside operations give passengers easy access but may pose problems of curb lane availability, service to adjacent properties, and right turn delays (unless right turns are prohibited).
- Median operations provide opportunities for either side or island platforms at stations and give a strong sense of LRT identify. They require wide streets, careful treatment of pedestrian access, and controlling conflicting left turns by a special traffic signal phase, or by restricting them.

Traffic Engineering and Operations Support

- Traffic signals should control conflicting LRT-vehicle movements. Special transit signal displays removed from vehicle indications are desirable (Figure 6-14).

Figure 6-14. Transit Signal

- For median signalized LRT operations, the signal phase for through-movements should follow the phase for the through vehicle-LRT movements. This phasing is essential to minimize same-direction conflicts between general traffic and LRVs.
- LRT traffic signal priorities are desirable to minimize delays along a route. LRT signal preemption (or activation) is essential where LRVs move on a separate phase to minimize conflicts.
- Traffic engineering actions, such as turn controls, street routing, and parking restrictions should support LRT operations while maintaining essential traffic circulation.
- Roadway geometry should reflect the physical and operating characteristics of LRVs, such as length, width, turning radius, and dynamic envelopes.
- Facility design should provide access to LRT rights-of-way and station areas to police vehicles, transit supervisors, tow trucks, and maintenance vehicles. Where LRTs operate in streets or alongside streets in separate rights-of-way, vehicle access is readily available. Ballasted segments of LRT alignments on separate rights-of-way should have a parallel roadway or nearby special easement for use by emergency and maintenance vehicles.

Station Areas

- Stations can be located on either the near-side or far-side of intersections. Far-side stations are necessary for LRT signal priorities as they enable left-turn lanes and station platforms to occupy the same road space.
- Station platform width should meet ADA requirements for the accessibility-impaired, including a 0.6-m (2-ft) tactile edge strip and a 2.4-m (8-ft)-minimum-wide platform. Station platform length should be governed by the largest train plus a short distance for passenger queuing/fare payment.
- Station platform height should be coordinated with the floor height of LRT cars. Both high and low platforms can be used as appropriate. In all cases, essential mobility for wheel chairs must be provided.

6.3 GEOMETRIC DESIGN FEATURES

Roadway and track geometry should be carefully integrated with traffic controls to achieve safe and efficient movement of LRVs and streetcars, general traffic, and pedestrians. This section provides general design guidelines for LRT in streets and highways.

6.3.1 Track Alignment Options

LRT may be placed in the center of roadways (including the left lane of divided highways), or in the right (curb) lane. Table 6-3 summarizes of typical track placement reflecting varying degrees of separation from general traffic. All have operated in U.S. cities and can be used to advantage. Table 6-3 also shows typical curb-to-curb roadway envelopes for track location options on one- and two-way streets. The envelopes are governed by the track clearances, station platform widths, and number of traffic lanes required. Where tracks cross bike lanes, a rubberized slip resistant surface should be provided.

LRT on one-way streets is generally less common than operations on two-way streets. Curb alignments generally need less walk space, since the station platforms are provided along the sidewalks. Center-of-the-road alignments pose potential conflicts with left turns, while curbside alignments pose potential problems of dealing with right turns and curbside access. Two-way operations along a two-way street can be confusing to crossing motor vehicles and pedestrians.

6.3.2 LRT in Mixed Traffic or Reserved Lanes

This section outlines design guidelines for LRT operations in mixed traffic, reserved lanes, bus-only lanes, or combined bus-LRT lanes.

Street Design Considerations

Streetcar or light rail transit tracks located in a shared right-of-way with other vehicle traffic should accommodate a maximum design speed equal to the legal speed of the parallel street traffic. Design features such as grade, vertical or horizontal curves, and track superelevation would be governed by this principle.

Tracks generally are located in the center of an undivided roadway, in the left lane of a divided roadway (where a wide median can provide space for stations or stops), or in the right curb lane. Location in the center of an undivided roadway can pose special challenges for stops, whereas light rail located along curb

Table 6-3. Light Rail Alignment Options and Design Implications (*31*)

Alignment Options for Location on Streets				Options for Location of Tracks					
	Type of Operation			Design and Operating Implications					
	Mixed Traffic	Reserved Lanes	Physically Separated Operation	Right Turns	Left Turns	Curb Access	Cross-Street Access	Off-Vehicle Fare Collection	Typical Minimum Curb and Width to Stations
Two-Way Streets									
Center of roadway: shared or reserved	X	X	X	OK	Permit from track or prohibit	OK	OK	At station	19–20 m (62–66 ft)
Center of roadway: physically separated			X	OK	Separate phase or prohibit	OK	OK	At station	24 m (80 ft)
Curb lanes	X	X		Permit from track or prohibit	OK	Precluded	OK	On (wide) sidewalk at stations	13–14 m (42–46 ft)
One side of street (segregated)			X	Prohibit	OK	Precluded on side of street	OK	On wide sidewalk at one side and station on other side	17 m (55 ft)
Separate right-of-way outside roadway right-of-way			X	Prohibit or special lanes	Prohibit or provide special lanes	OK	May be confusing to cross one-way street	At station	13–20 m (44–65 ft)
One-Way Streets									
Center of roadway (shared or reserved)	X	X		OK	OK	OK	OK	At station	13 m (44 ft)
Curb lanes, normal flow (shared or reserved)	X	X		Permit from track or prohibit	OK	Precluded on one side	OK	On (wide) sidewalk at stations	10 m (33 ft)
Curb lanes, contra flow (reserved or segregated)		X	X	OK in other direction	Prohibit or provide special lanes	Precluded on one side	OK	On (wide) sidewalk at stations	10–13 m (33–44 ft)
Two-way on side of street (reserved or segregated)		X	X	OK	Prohibit or provide special lanes	Precluded on one side	OK	On wide sidewalk at one side and station on other side	13–17 m (44–55 ft)

lanes poses challenges of providing adjacent property access and dealing with general traffic right turns. Turning motor vehicles may compromise safety, so turns may have to be restricted, limited to specific locations, or carefully accommodated.

The location of transit tracks within any given roadway is governed by many factors. These include the following:

- Overall roadway and sidewalk widths;
- Curb access requirements;

- One-or two-way street operation;
- Ability to restrict or accommodate turning traffic;
- Pedestrian access requirements; and
- Physical dimensions of the vehicle and its dynamic envelope.

The impacts of the dimensions of the vehicle are obvious and do not differ much from standard bus dimensions. The requirements imposed by the dynamic envelope are perhaps not as intuitive. The vehicle "dynamic envelope" is the extreme limit that the vehicle may reach while in motion, taking into consideration lateral, vertical, and rotational vehicle body movements that occur when operating on straight track. The vehicle dynamic envelope may be thought of as the cross section of the vehicle for design purposes, but without construction tolerances, maintenance tolerances, and running clearances added. In addition to car body movements on straight track, the effects of track curvature and superelevation also must be considered. On curved track sections, the dynamic envelope must be adjusted for the end overhang and middle ordinate shift of the car body and for superelevation. Location of the tracks within the travel lane must accommodate the potential effect of the vehicle's dynamic envelope upon parallel traffic, as well as upon other wayside factors, such as utility poles, traffic signs, station structures, and passenger waiting areas. Refer to Chapter 3 for the LRT dynamic envelope.

Platform Design Considerations

Streetcar and LRT station stops are similar. They both should be designed to provide a safe and convenient refuge for waiting or alighting passengers. Unlike buses, many streetcars and most LRVs have doors on both sides of the vehicle. This provides more flexibility in station platform location. For example, streetcars or LRVs in the left travel lane can have stations on a wide median.

Factors to consider in the location and design of LRT and bus-LRT station platforms include:

- ADA requirements;
- Available street and sidewalk widths;
- Anticipated peak-hour ridership;
- Lengths of train consists (one-, two-, or three-car consists, for example); and
- The possible number of LRT vehicles and buses in the station at the same time.

ADA requires that new transit facilities to be accessible to the disabled, meaning curb cuts for wheelchair access, tactile warning strips at edges for the visually impaired, and adequate space allowances for wheelchair maneuvering, among others. This translates into a minimum platform width of 3 m (10 ft). For vehicles that lift wheelchair patrons mechanically, it may be necessary to widen the platform dimensions to allow space for the lift and adequate space beyond the lift for wheelchair maneuvering.

Station platforms should provide enough space to accommodate the peak anticipated number of people that will be there at any given time. The length of the transit trains, expected volumes of passengers, and configuration of the site all influence platform design. Along narrow streets, where traffic conditions permit, it may be desirable to close the street to general traffic in the station block and create a mini-transit mall.

LRT stops should be long enough to accommodate the longest operating train. Where a stop serves both buses and streetcars, it should be long enough to accommodate the simultaneous stopping of a streetcar or LRV and bus.

Most municipalities will specify curb height and designs. Local ADA requirements and accommodations must be met.

At busy intersections or where platforms are adjacent to lanes with heavy volumes or high-speed traffic, a fence or another type of barrier can be installed at the platform edge (except where the transit vehicle doors must be accessible). Short poles connected by chains or a short fence can line a station platform to discourage pedestrians from crossing traffic lanes. Usually such barriers are designed to channel the pedestrian traffic to a crosswalk or other protected crossing.

Some transit agencies have adopted policies to facilitate travel by bicycle on transit. Generally, there are limitations on the number of bicycle patrons permitted—such as fixing the number of bicycles per vehicle or restrictions during peak periods. It is common to see transit buses with bicycle racks, but not so for streetcars or LRT vehicles. Because streetcars have limited space and ADA requirements (wheelchair lifts and collapsible seating area) require some of that space, few agencies allow bicycles on-board streetcars. Larger LRVs are better able to accommodate bicyclists, but like commuter railroads, they often restrict such access during morning and evening peak periods. To promote this mode, bicycle racks, lockers, or storage units may be located at stations to permit bicyclists to transfer to LRT without needing to transport their bicycles.

Intersection Considerations

Intersections, especially signalized intersections, are a major concern facing in-street LRT operation. This section outlines the geometric, safety, operational, and signal aspects of LRT facilities at intersections, and the relationship between LRT stops and intersection proximity/design is discussed. Unsignalized intersections also are addressed.

As noted, rail transit vehicles are similar to rubber-tired buses in many ways, so planning and design for both modes share common issues. Because transit vehicles are large, their traffic flow impacts should be mitigated by keeping the larger vehicles moving and helping them clear intersections quickly. In addition to signal priority, LRT vehicles can have separate signal systems that coordinate transit vehicle movements through complex intersections (see Figure 6-14).

Signalized Intersections. In general, signalized intersections have large volumes of traffic; significant turning movements and many potential conflicts and complex geometries that require signalized traffic control. Traffic signals control conflicting movements and facilitate improved flow where traffic volumes are high. If the LRT passes through an intersection, it can be treated similarly to other modes; however, complex intersections may require more specific design treatment.

Where an LRT route turns at an intersection onto the cross-street, signal controls must provide a separate phase for the transit vehicle to make the turn and clear the intersection. For example, if the LRV is turning right at an intersection from the left travel lane (adjacent to the median), conflicting parallel traffic must be held back while the vehicle crosses those lanes. Railroad gate arms are sometimes employed to stop traffic. Similarly, cross-traffic moving from left to right must be stopped while the LRV crosses those lanes. During this phase of the cycle, it may be possible to permit right turns for the non-conflicting parallel traffic and left

turns for the cross-traffic, and it may be possible to permit oncoming traffic and cross-traffic moving from right to left to proceed through the intersection, as these movements do not conflict with the LRV's turn. The special signal phase can be activated track detectors that sense when the LRV approaches and clears the intersection.

If the LRT route turns left at the intersection, similar restrictions on conflicting movements should be incorporated into the signal cycle. In this case, it may be desirable to shift the LRT tracks into a median to provide a space outside the active traffic lanes for the LRV to await the left-turn signal without blocking other vehicle traffic from behind.

If the LRT tracks are in the right travel lane (adjacent to the curb), a right turn may not involve as many potential conflicts nor necessitate a separate signal cycle for the LRV to turn. If the LRV is turning left at an intersection, more complex traffic controls will be necessary as the LRV will cross virtually all traffic lanes during the turning movement, requiring a separate LRV signal phase.

Unsignalized Intersections. Unsignalized intersections usually have lower traffic volumes, fewer turning conflicts, and less complex geometries. If the LRT route turns onto the cross-street, it may be necessary to introduce a traffic signal at the intersection to protect that movement, but if the LRT route passes through the unsignalized intersection, there is less need for special controls. The traffic signal warrants in Part 4 of the MUTCD must be met to install traffic signals at the intersection. If the traffic signal warrants are not met and traffic must be stopped the signals must conform to Part 8. (*28*) If traffic volumes are low, but pedestrian volumes are high (e.g., adjacent to a school or other pedestrian traffic generator), the LRV may be required to stop at the intersection (the equivalent of a stop sign rather than a traffic signal) before proceeding. This practice may apply to an unsignalized intersection where the LRV must cross a very wide boulevard or heavily traveled arterial.

If rail transit has not been a familiar feature in a community (or if it has been absent for a generation or more), it may be advisable to launch a public education program advising motorists of LRT operations and situations where motorists should yield to transit vehicles. This education program, in coordination with proper signing and striping, can help minimize conflicts and confusion. The LRV typically has the right-of-way, and motorists yield to the train. This is especially important at unsignalized intersections, U-turn locations, and places where motorists typically turn left to enter driveways or parking lots. Attempts should be made to close left-turning access to some minor cross streets, channelize medians, and perform other measures to restrict track crossing to major, well signed and signalized locations.

Stop Locations Relative to Intersections. Intersections often serve as convenient LRT stop locations because they traditionally offer a concentration of destinations and potential transfer opportunities for transit service on the cross-street. Similar to bus stop location principles, LRT stops should be placed at or near intersections with consideration given to minimizing potential traffic conflicts. In some instances where the LRT line is in an active traffic lane, locating the transit stop too close to the intersection could interfere with other vehicle-turning movements, or it may be advisable to create a turnout for the LRT to be removed from the traffic lane only at the stop site. Space configurations may dictate the plausibility of design solutions. In any case, care must be given to provide the transit patrons with safe, convenient options to access destinations near the intersection or other transit stops at the intersection for transfers. Far-side stops are essential where traffic signal priorities are provided.

6.3.3 Separated Light Rail and Shared Bus-Rail Facilities

Segregated facilities in exclusive rights-of-way may include operations in subway, elevated lines, freeway envelopes, and private rights-of-way. Semi-exclusive operation occurs within the median areas of arterial streets and roadways. Guidelines for separated light rail or shared bus-rail facilities in arterial street environments follow.

Cross-Sections and Design Considerations

Roadway and track cross-sections depend upon the available rights-of-way, the need for stations and left-turn lanes, and the number of through-travel lanes and parking lanes required.

- Tracks typically occupy 6.7 to 8.0 m (22 to 26 ft). Each side station platform adds about 3 m (10 ft). Left-turn lanes can be provided on the near-side of intersections and stations on the far-side, allowing both to occupy the same space. Two lanes for general traffic should be provided in each direction. This results in a curb-to-curb width of at least 27.5 m (90 ft).
- A smaller envelope is possible where left turns can be prohibited at station locations. This can be accomplished in two ways:
  1. Shifting the track alignment across an intersection so that the platform in each direction can occupy a single 3.0 m (10 ft) space; or
  2. Using a single, center island platform.
- Station design and roadway travel lanes should be adapted to available rights-of-way by prohibiting left lanes, using island platforms, or reducing the number of travel lanes. Figure 6-15 illustrates examples for 39-, 36-, and 20-m (131-, 120-, and 66-ft) rights-of-way.
- Tracks may be embedded in pavements or be ballasted track. In the latter case, grass can be planted within the running way to achieve an aesthetically pleasing appearance and better sound and rain water absorption.
- Frequent crossovers or turnouts are desirable to enable LRVs to pass around stalled trains to reduce systemwide delay. Turnouts (e.g., short spurs [tail tracks]) are desirable where space permits. They provide space onto which a stalled LRV may be removed from the active tracks until maintenance activities can be performed.
- Curbing, raised traffic buttons or other forms of physical delineation should physically separate the tracks from the adjacent traffic lanes (Figure 6-16). Along high-speed arterials (speeds more than 65 km/h [40 mph]), track curbs may be desirable.
- Fencing may be provided between tracks at stations to discourage pedestrians from crossing. This treatment may also be provided between the tracks and general-purpose lanes, where there are school children and pedestrians in areas of train movements.
- Unused space between the tracks and roadway areas is often landscaped with low shrubbery to maintain lines of sight to no more than about 0.9 m (3 ft), shown in Figure 6-17. These areas also could be used for parallel parking, especially where parking is prohibited along the curb.

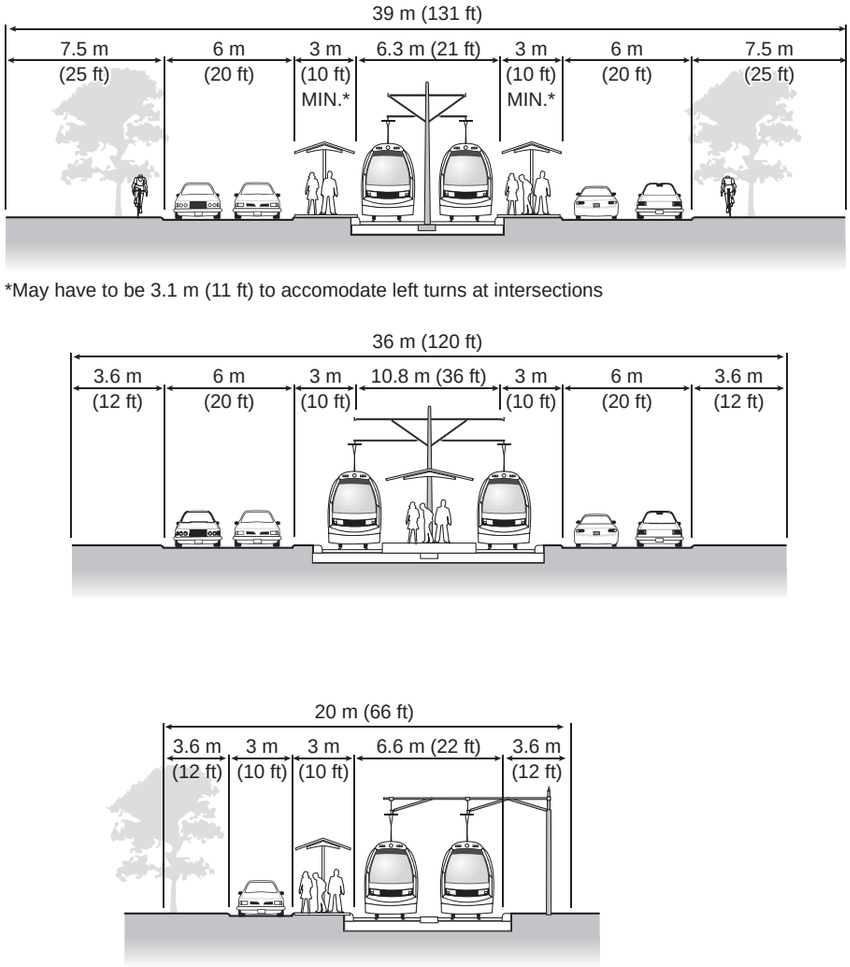


Figure 6-15. Station Design and Roadway Travel Lanes Adapted to Available Right-of-Way (*10*)

- Intersections with major cross-streets generally should be signalized. A special phase for left-turn movements should follow the combined LRT/through movement phase to minimize the likelihood of same direction LRT-car collisions.

Where a trackway serves both LRVs and buses, the surface treatment must accommodate both types of vehicles. Pavement should meet design standards for each design vehicle in terms of lane width, sight distance, and curvature. Sufficient crossovers and pullouts for failure recovery should be provided. Platform height, design and location should be compatible, and common transit signal displays and controls should be used.

Guideway design considerations may be part of a larger civic program to enhance the appearance of a corridor. This may include decorative pavement, art at transit stations, street furniture, banners or hanging plants on light standards, enhanced landscaping, etc. Potential rail transit investments often are an element of larger civic programs for revitalization and economic development. Often, local governments or civic groups will finance parts of the corridor improvement initiative while the federal government will finance the transportation elements.

Figure 6-16. Example of Raised Traffic Delineation

Figure 6-17. Example of Landscaped Median Around LRT Tracks

Station Design Considerations

Depending on local conditions, space availability, and other factors, a variety of configurations can be designed to allow exclusive LRT or rail-bus shared operations. These same factors or others may govern station platform location (side orientation or center orientation). Generally, it is more economical to build a single center platform than two side platforms, but this is not practical for shared LRT-bus operation unless buses have doors on both sides, as exemplified in Cleveland's BRT line).

- Stations must be designed with the LRT vehicle size in mind. If the vehicles are coupled into trains, the station must be designed such that a stopped LRT vehicle in the station does not overhang the station and affect neighboring intersections.
- There should be sufficient space for crowds to assemble for boarding, clearly marked safe channels for pedestrians to enter and exit the station, and appropriate barriers to prevent pedestrians from walking from the LRT station into a moving traffic lane. Adequate pedestrian space on a center platform must be planned for the simultaneous presence of two trains (one in each direction) at the station, including the possible simultaneous operation of mechanical wheelchair ramps (if they are part of the LRT vehicle) from each train onto the platform. Bicycle storage should be provided.
- While in the station, transit vehicles may be isolated from other traffic, but consideration should be given to potential conflicts when the vehicles leave the station. Stations near intersections must account for potential turning movements by transit or other traffic, and this often requires signalization. If the LRV or bus must leave the exclusive right-of-way, even for a short distance, traffic signals may be needed to hold conflicting traffic long enough for the bus or rail vehicle to leave the station and enter the traffic lane.
- If LRVs share the facility with buses, attention must be paid to platform design. In Calgary, buses and LRT vehicles operate on an exclusive transit mall downtown. The LRT stations have high platforms for easy movement of passengers onto and off the vehicles. Consequently, buses stop at at-grade locations adjacent to the rail stops, and bus passengers board and alight at ground level.

Intersection Treatments

Many of the concerns discussed in Section 6.3.2 apply to light rail or shared LRT-bus facilities running in a street median. As noted, rail transit vehicles are large, and traffic flow impacts should be mitigated by keeping the larger vehicles moving and helping them clear intersections quickly. An "exclusive" transit facility in a street median is exclusive only between the cross-streets, and whenever the transit vehicles leave the median running way, they should be protected from potential conflicts with other traffic. The same guidance for signalized intersections, unsignalized intersections and stop locations presented in previous section 6.3.2 applies.

6.4 STOP AND STATION DESIGN

This section discusses street-level light rail stops and stations that are incorporated in the arterial roadway environment. Elevated alignments outside the street environment and subway stations are not addressed.

The station planning and design process has two phases that overlap and interact. In the first phase, specifications and criteria that apply to all stations on a line or section of a line are determined. Such

specifications and criteria include design features of the vehicles to be used that, once fixed, govern station design features. For example, if the vehicles are designed for only low-level or only high-level platform boardings, then all stations must be designed accordingly. Other standards, such as platform length and width, minimum curvature in stations (if any), and architectural design may be set for a specific line or entire system, but may be more flexible where conditions warrant. All stations must meet ADA accessibility requirements for the mobility impaired.

The second phase addresses specific requirements of each station. Designs should reflect each station setting and space constraints and may call for modifying system standards. For on-street stations, variations may include configuration of the platforms, tracks, roadway, turn lanes, traffic and pedestrian access patterns, platform width, arrangement of walkways and crosswalks, and station amenities such as shelters, benches, vending machines, ramps, passenger information, and landscaping. Stations should be both functional and attractive. Their designs often are keyed to their adjacent land use and integrated with urban design themes for surrounding areas. They may also provide a distinctive image or theme.

6.4.1 Station Location

Stations should be located at major passenger attractions, on cross-streets with bus lines and, in some cases, where land is available for park-and-ride facilities.

LRV (or streetcar) operations should be considered in locating stations. Vehicle operations should have a clear view of pedestrians, waiting passengers, and motorists as they approach stations. Sharp curves with limited visibility, steep grades, and sharp vertical curve crests should be avoided on station approaches.

Station platforms should be as close to level as possible, preferably with slopes limited to one or two percent. ADA guidelines recommend that the gap between the rail vehicle floor and the platform be no more than 76 mm (3 in.) horizontal and 16 mm (5/8 in.) vertically. ADA requirements dictate that platform edges be tangent and parallel to the vehicle and have no vertical curvature

Stations may be located along the sidewalk where LRT operates in curb lanes. These curbside stations provide convenient passenger access but require wide sidewalks where off-vehicle fare collection requires a "paved" area to monitor fare payments. Platform heights that vary from the boarding area and adjacent sidewalk requiring rail or landscape berm separation.

Stations for center running LRT require careful design to ensure pedestrian safety and to "transition" vehicle traffic around the ends of the stations. The stations work best when the tracks (or combined LRT-bus running way) are segregated from the traffic lanes and there is adequate road space to accommodate all movements.

The operating environment at a signalized intersection, along with the available roadway width, may govern the best location for a stop. As with bus stops, the location of LRT stops may be near-side, far-side, or mid-block. Far-side stops are essential where transit signal priorities are provided. For median running LRT, far-side stops enable the stop and left-turn lanes to use the same roadway space.

When LRT operates in mixed traffic in curb lanes and stops on the near-side, it can affect right turns for motor vehicles. Thus, unless turns are prohibited, far-side stops are preferable.

6.4.2 Station Spacing

The type of operation (LRT, streetcar, heritage trolley) and the density of development will influence station spacing. Stations should be spaced closely where transit riders walk to and from stations (as in central areas), at about 0.8 to 1.0 km (0.5 to 0.6 mi) where passengers arrive by intersecting bus lines, and 1.6 to 3.2 km (about 1 to 2 mi) in suburban areas.

LRT station spacing can be as low as 200 m (660 ft), or every second short city block, which would mean that almost anyone living or working in the corridor could walk to and from a stop. This is the standard for streetcar design in various cities. The overall running speed, however, will be slow because of the many stops and starts along the line. In contrast to such "local" service, LRT stations can instead be placed about 1 km (3,000 ft) apart, which would require feeder services to bring patrons from large tributary areas to the line.

In many cities, such as Baltimore and Buffalo, stations in the urban core are close to one another to serve dense development areas with many traffic generators, while stations on the outer portions of the route are farther apart to serve only major generators or large park-and-ride facilities. The usual range for station spacing appears to be 350 to 600 m (1,000 to 2,000 ft), except for outlying, low-density areas.

6.4.3 Platform Orientation

Light rail stations for median running can be a single center platform with a track on each side, or side platforms. Figure 6-18 illustrates examples of each. In both cases, at-grade access is limited to the ends of the platforms, capacities are limited by the width of platforms or must be able to clear passengers in the interval between trains.

Side Platforms

Side platforms enable tracks to be placed close to each other. The catenary support may be placed between the tracks. They are common where single tracks operate a split pair, and where large numbers of

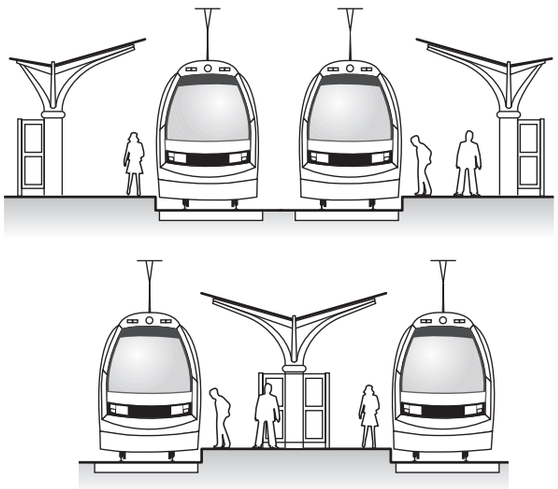


Figure 6-18. Typical Platform Cross-Sections for Light Rail Stations

passengers approach stations from an adjacent area (e.g., at a stadium). Side orientation is also used where buses and rail vehicles share the same running way. Fencing or barriers are needed to protect passengers from the adjacent travel lanes. The degree of protection depends on the design speed and type of adjacent roadway.

Median (Center) Platforms

The median platforms require less space than a pair of side platforms, and are usually less expensive to build. They work well where there is a tidal flow of passengers, e.g., to the CBD in the morning and from the CBD in the evening. They are common on rail facilities that have doors on both sides. When LRT operates within a segregated median running way, passengers are isolated from the vehicle traffic along the roadway.

6.4.4 Platform Elements and Dimensions

Station platform design elements include size, height, and layout, accommodations for the mobility impaired, bicycle storage, and provisions for passenger waiting and fare collection. These elements are governed by:

- Relation of station platform to the surrounding streets and intersections;
- Anticipated ridership during peak (rush) hour; and
- ADA requirements such as wheelchair mobility.

Integration into Street Systems

The design of the stations should be integrated with the surrounding street or nearby intersection. Thus, design elements include elements of the street or intersection, such as traffic lanes, turn lanes, crosswalks, and signals, in addition to those elements directly related to the light rail line. In determining the station design, conflicting issues must be balanced, and design features must respond to each other and to the physical constraints of the site. The platform, a central element of station layout, may be clearly visible and discrete or it may be integrated into a sidewalk with no apparent distinction between walkway and loading area (*30*).

Anticipated Ridership

A critical factor in estimating platform size and pedestrian access to stations is the future peak-hour ridership. Demand modeling performed during planning stages is useful in estimating possible ridership. Such ridership estimates should be checked for reasonableness.

Mobility Requirements

LRT stations must be designed to accommodate the needs of individuals with disabilities. Ticket vending machines and validations must be usable by individuals with vision and mobility impairments. Accessible paths of travel must be provided that are comparable with paths of travel provided for unimpaired riders. A detectable warning strip 0.6 m (2 ft) wide is required along platform edges or other drop-offs not protected with railings or other barriers. Vertical level changes require ramps or elevators.

All light rail systems must include boarding and alighting provisions that accommodate wheelchairs.

- High-level platforms match the elevation of car flow, typically 0.5 m (1.5 ft) above the top of rail. High-level platforms allow faster boarding and alighting and can reduce dwell times at stations. They

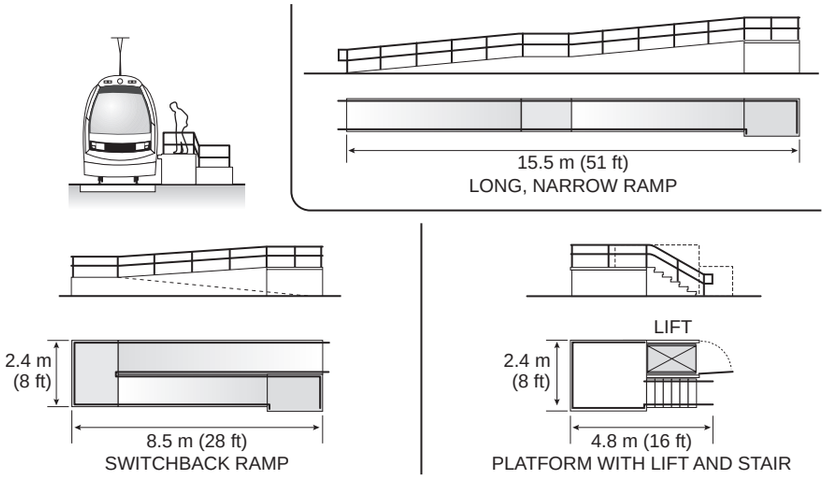


Figure 6-19. Mini-High Platforms (*30*)

provide safe entry and exit for all passengers. Wheelchair users may enter or exit cars from all doors. However, they cost more to build, may be difficult to construct in constrained rights-of-way, and are impractical along sidewalks.

- Another option is to build short, high platforms at each stop to reach only the front door of a vehicle by means of a wheelchair lift. Figure 6-19 illustrates an example of such a treatment. These "mini-high" level platforms are usually reached by ramps from the low-level sections of the platform and they require deployment of vehicle-mounted bridge plates to span the gap between the vehicle and the platform (*30*).
- Conventional LRVs have floors roughly 750 mm (30 in.) above the top of rail. Most of these vehicles require passengers to climb three or four steps to enter the vehicle. Mobility-impaired passengers are accommodated by on-vehicle or wayside lifts.
- Low-floor LRVs have all, or parts, of the vehicle's floor at a level roughly 340 mm (13 in.) above the top of rail. Doors in the low floor portions of the vehicles may be boarded directly from platforms at floor height, or from platforms at a nominal 150-to-180-mm (6-to-7-in.) curb height using short bridge plates deployed automatically from the vehicle.

Platform Width

Platform width should be determined individually, based upon ridership, available space, ADA requirements, and local codes and standards for passenger queuing and evacuation. Minimum platform widths must accommodate a 0.6-m (2-ft) detectable track-edge warning strip and allow unobstructed passage for wheelchairs and pedestrians adjacent to the warning strip. Consequently, side platforms must be at least 2.4 m (8 ft) between the platform edge and any obstruction. This translates into at least 3.6 m (12 ft) of width. However, a 4.5-m (15-ft) width is desirable where possible. Widths for center platforms should be at least 3.6 m (12 ft). A 4.5-m (15-ft) width is desirable where possible.

Platform Lengths

Platform lengths should be designed to accommodate the largest train normally used. Thus, they depend upon the length of each car and the number of the cars consistently using the platform.

Making platforms longer in anticipation of an increase in demand may not be affordable, but reserving space for such a possible expansion is advisable, as long as cross-street spacing is adequate. Where the LRT line is run along the curb, the entry/exit arrangements can be accommodated more directly, but parking space would be lost and shelters, and other passenger amenities may consume sidewalk space.

Typically, LRT trains are one to four cars long, resulting in lengths up to about 110 m (360 ft). Platform lengths should be able to accommodate the car length plus additional length at the ends of platforms to accommodate queuing at end doors, fare collection areas, and variations in train stopping distances.

Some LRT stations may have "free" and "paid" areas where off-vehicle proof of payment is used. This permits fare payment inspection in stations before passengers board the LRV. Additional station length is desirable to accommodate this function. "Free" areas must have adequate space for ticket vending machines and passenger queuing. Good signing is essential. A guideline for signing is contained in *TCRP Report 12—Guidelines for Transit Facility Signing and Graphics,* 1996. (*22*)

Amenities and Facilities

Passenger waiting areas for light rail stations generally include limited amenities. Most stations have canopies covering part of the platform. Most also have some vertical surfaces that are usually transparent to maintain visibility while providing limited protection from wind and wind-driven precipitation. On exposed platforms, especially in colder climates, more extensive passenger shelters are often used, with enclosures on all sides. In some cases, heating is provided. Limited seating and leaning areas are usually provided on platforms. Good lighting and signing should be provided. Signing and lighting may be solar powered to reduce operating costs.

Typical Station Designs

Figures 6-20 and 6-21 illustrate examples and dimensions of typical center platform and side platform stations within roadway rights-of-way, respectively.

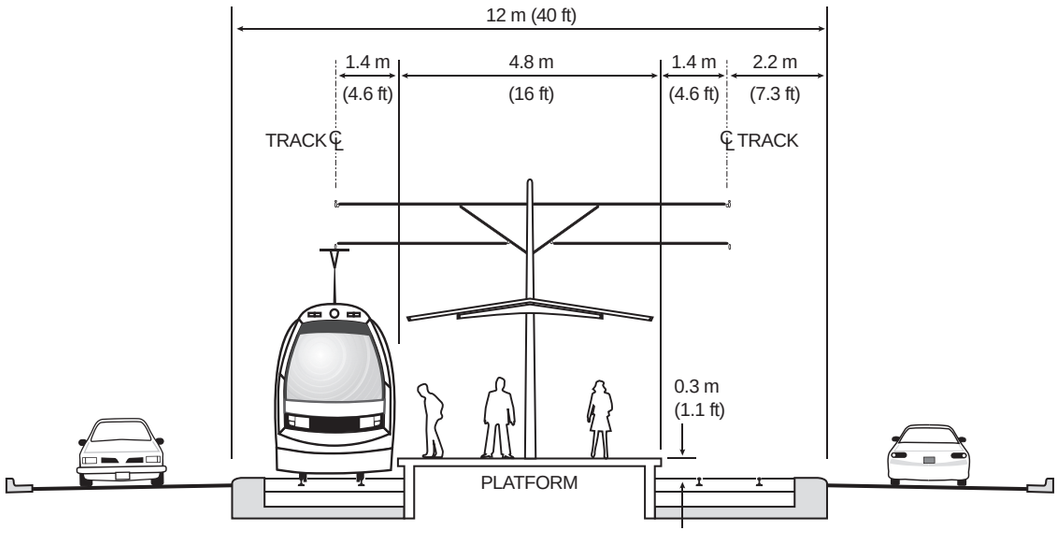


Figure 6-20. Exclusive LRT Median Station Within a Roadway (High-Platform Station) (*18*)

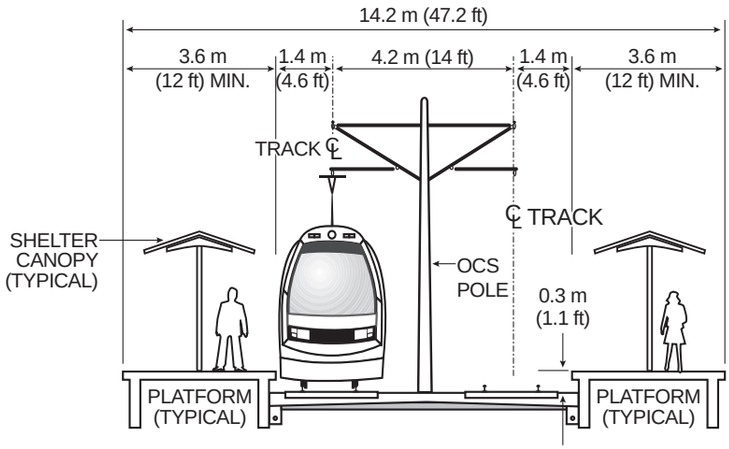


Figure 6-21. Exclusive LRT Side Station Within a Roadway (High-Platform Station) (*18*)

6.4.5 Station Configuration Examples

Figure 6-22 illustrates examples of LRT station configurations for both in-street and off-street alignments.

- Far-side stops are provided for center running LRT in (a) mixed traffic and (b) segregated running ways. In the first example, left turns could be made from the tracks or they could be prohibited. In the second example (b), a left turn is made from a separate lane and could have its own protected movement.
- The station for a reserved running way on the side of a street (example c) has a recessed drop-off lane for passenger drop-off and pickup, or for bus stops.
- Side platform orientations for LRT (example d) are preferred to keep from deviating track alignment; however, they require dual sets of passenger access for both platforms.
- A center platform orientation (example e) works better where passenger transfers occur between different routes or services, and require only one set of vertical circulation, but also a wider platform.
- Figures 6-23 through 6-27 illustrate detailed examples of LRT station configurations in roadways.
- Figure 6-23 illustrates a station arrangement for LRT running in mixed traffic in the curb lanes. The stations are located along the sidewalk in the same city block. An alternative would be to provide far-side stops.
- Figure 6-24 illustrates LRT running in mixed traffic in lanes alongside a wide median. A single median station is provided. General traffic left turns should be prohibited from the tracks to minimize conflicts with the trains. This treatment eliminates curbside friction. Designers should be careful to provide safe pedestrian access from the curbs to the median.
- Figure 6-25 illustrates a center island station for LRT operating in segregated lanes. Where space is limited, left turns can be prohibited.
- Figure 6-26 illustrates far side-platform-station arrangements on opposite sides of the intersecting street, and left turns are prohibited. An alternative arrangement is to provide the stations located

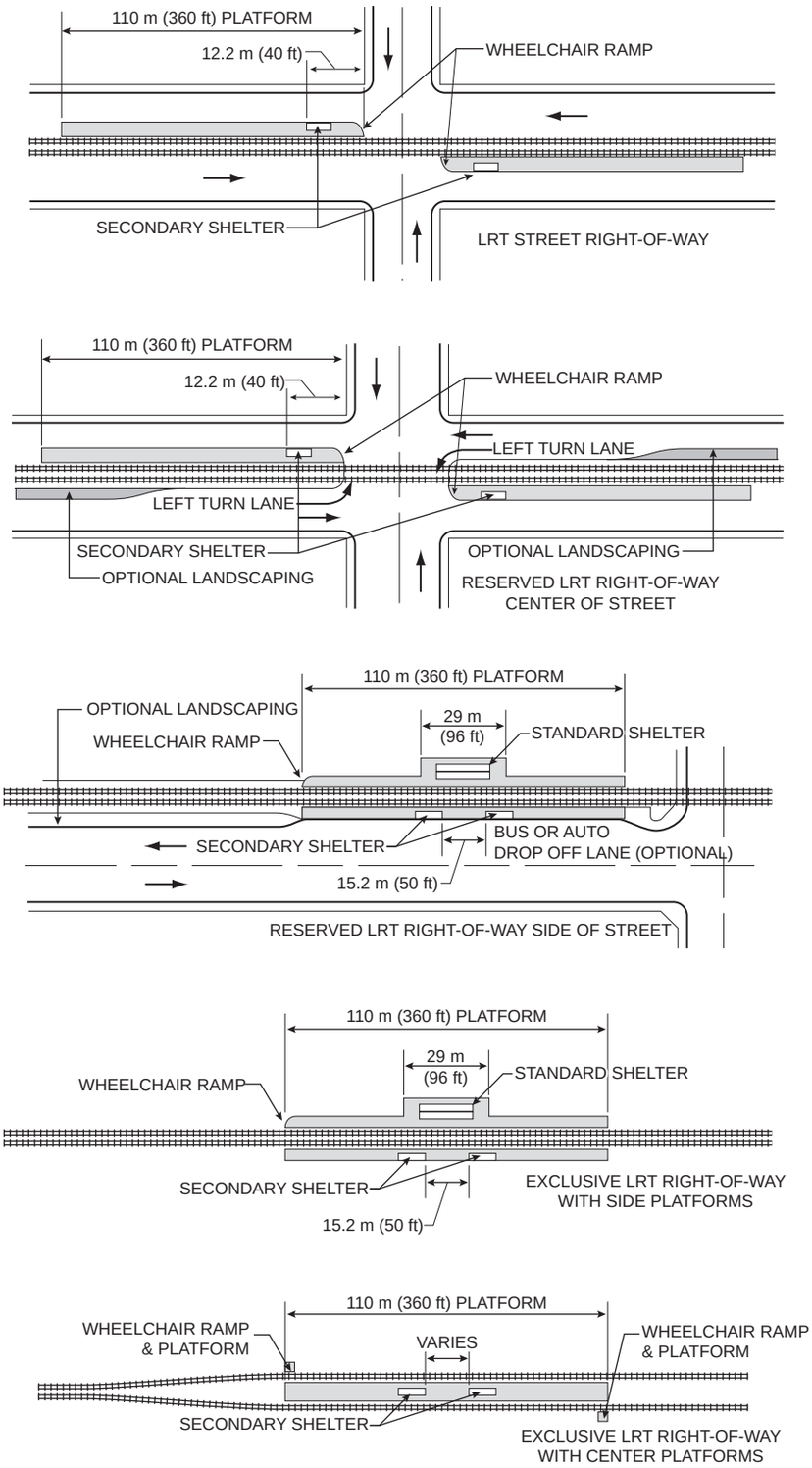


Figure 6-22. Typical LRT Station Configurations (*6*)

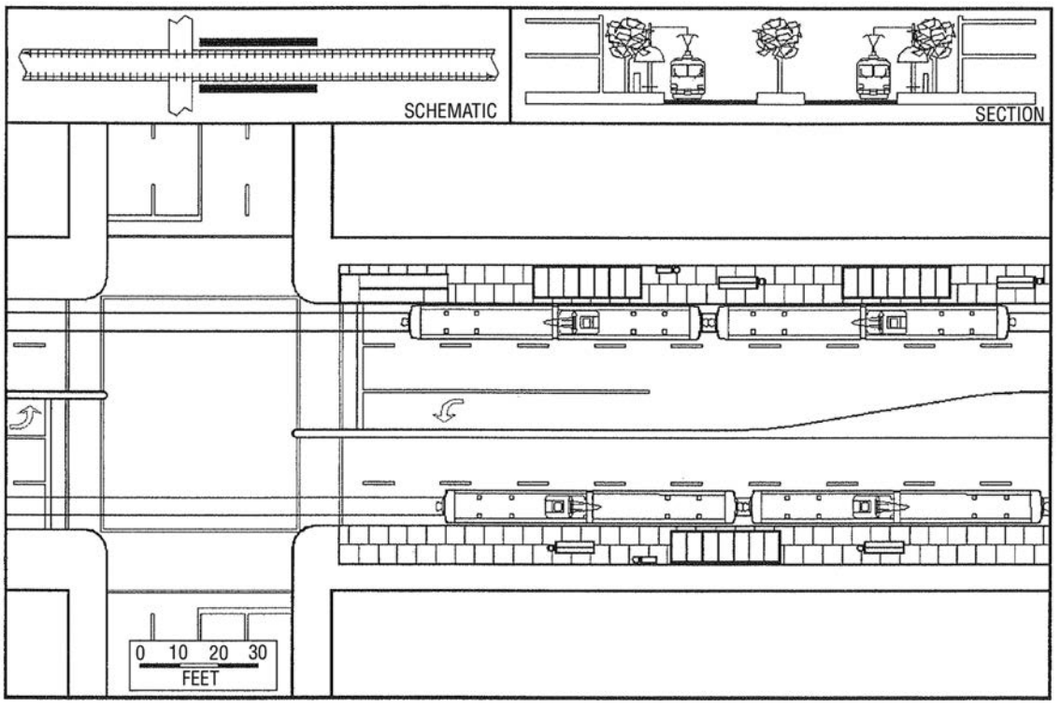


Figure 6-23. Sidewalk Platform Station for LRT in Mixed Traffic (*30*)

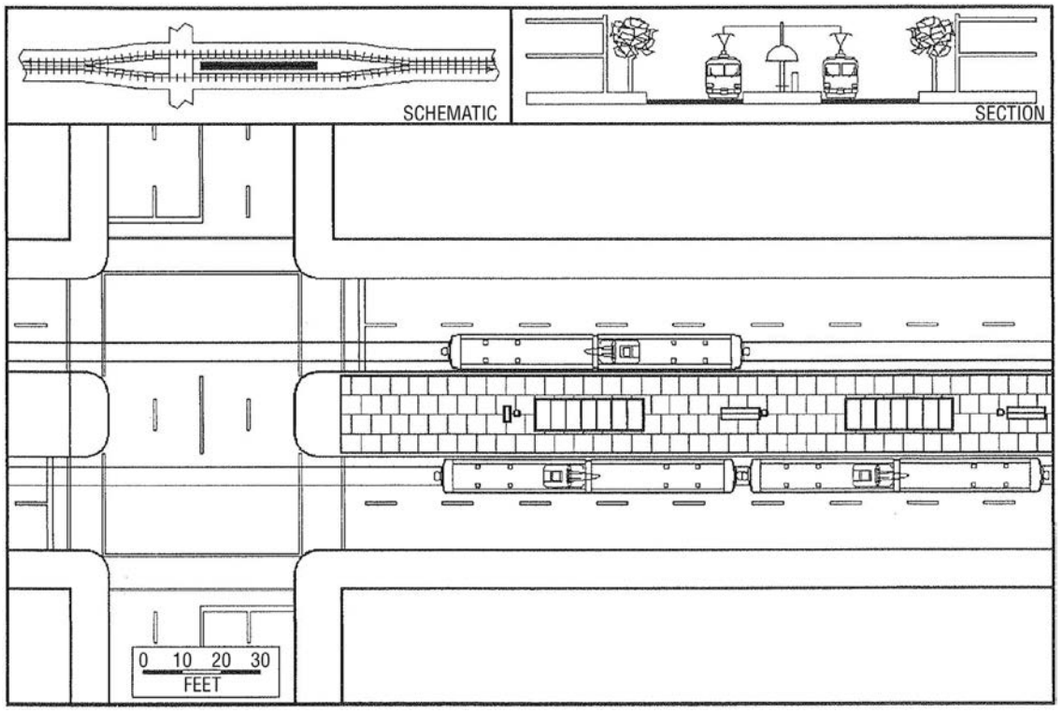


Figure 6-24. Center Platform Station in Median for LRT in Mixed Traffic (*30*)

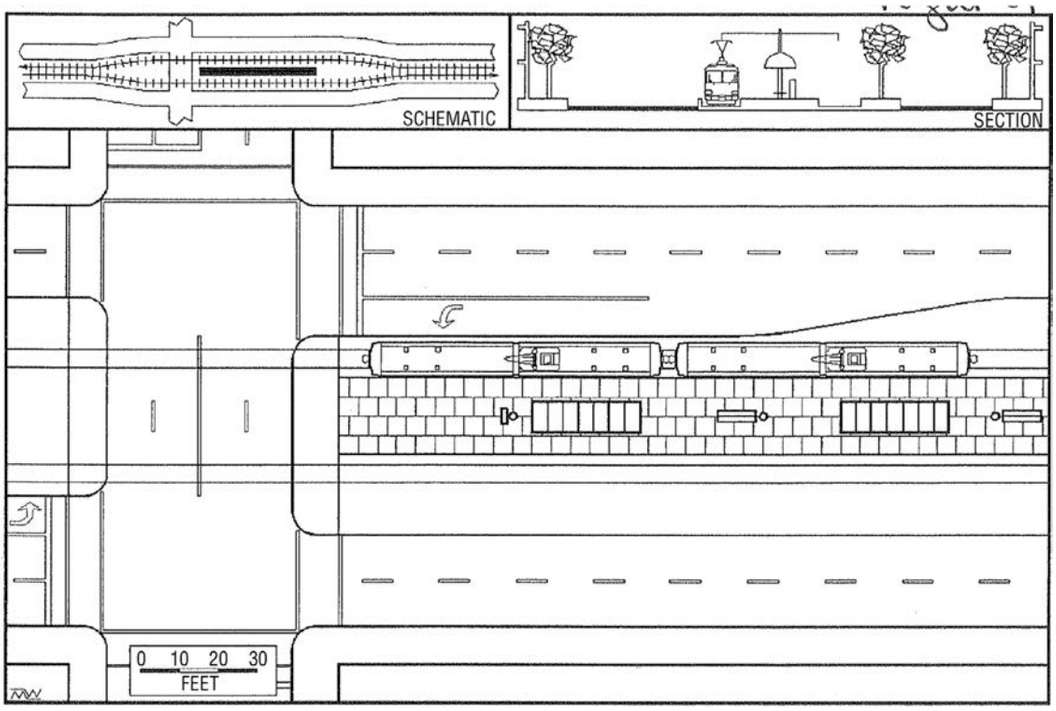


Figure 6-25. Platform Station in Median for LRT on Exclusive Right-of-Way (*30*)

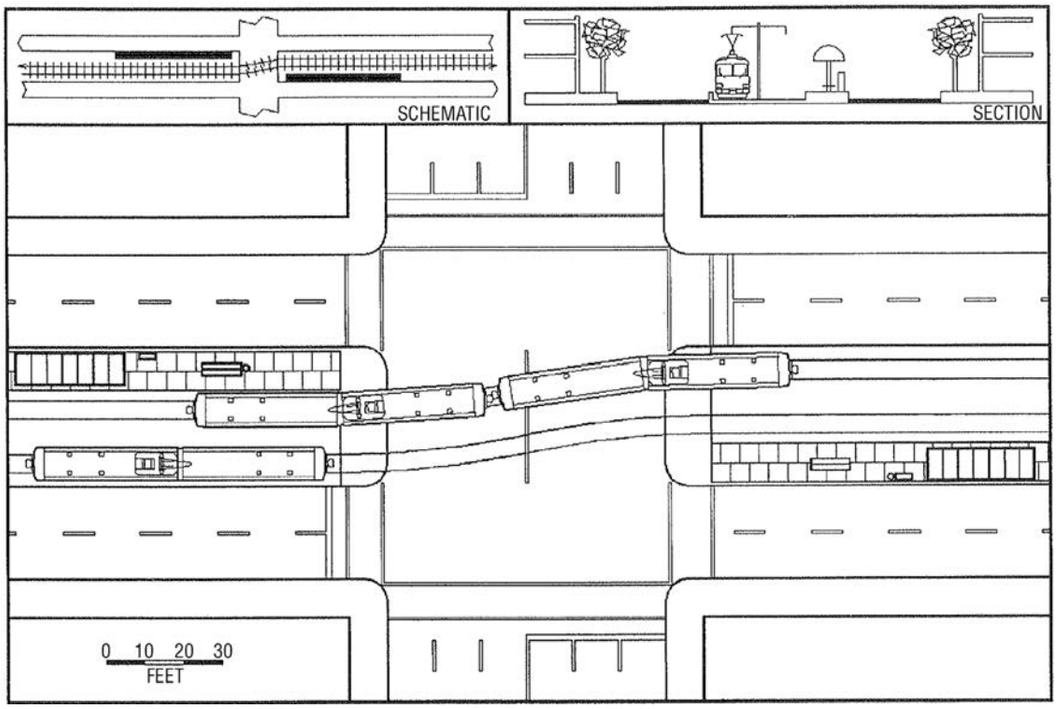


Figure 6-26. Far-Side Split Platforms in Median for LRT in Exclusive (Minimum) Right-of-Way (*30*)

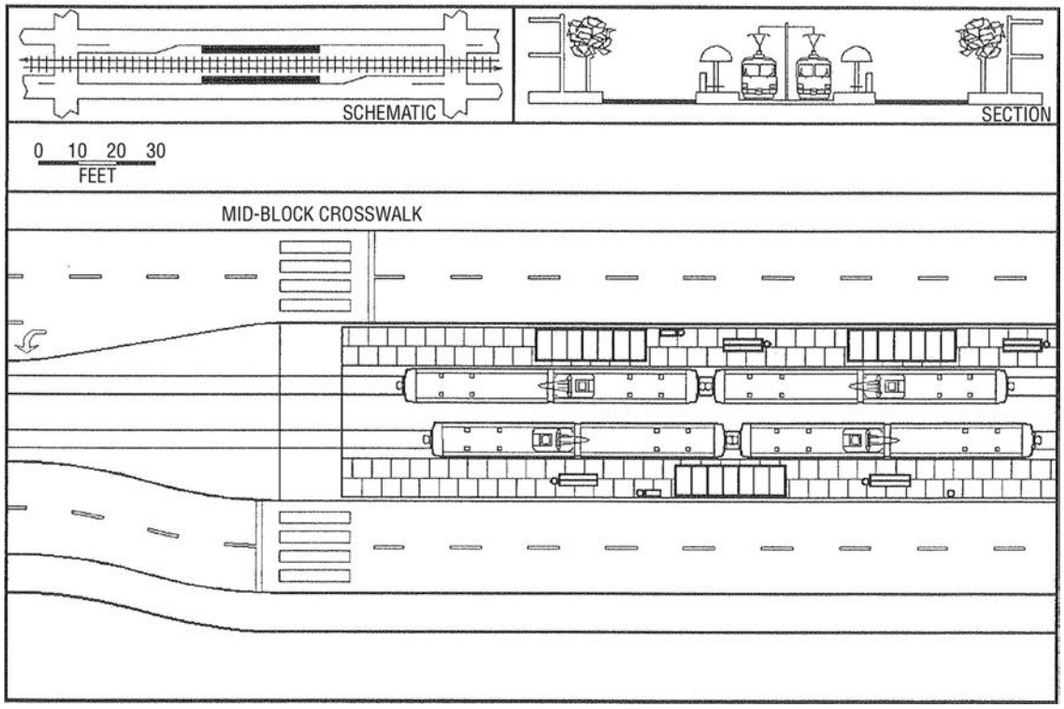


Figure 6-27. Mid-Block Side Platform Station in Median for LRT in Exclusive Right-of-Way (*30*)

alongside each other far-side stops with "split" platforms on separate sides of the cross-street. Near-side, left-turn lanes for general traffic can then be provided in both directions.

- In some instances, especially where median width is limited, it is possible to split the station and to place a platform on both sides of the intersection (Figure 6-26). Access to platforms may be limited to one or both ends of the station or, if traffic is light and low platforms are used, crosswalks to adjacent sidewalks can be located along the length of the station. In this arrangement, left turns are prohibited at the intersection.

- A mid-block station may be located where a major trip generator or pedestrian route is located between intersections. A mid-block location also avoids congestion and the competition for limited space at intersections. Figure 6-27 illustrates an alternative side platform station in the street median at mid-block with the light rail tracks in an exclusive right-of-way. The mid-block median station location allows left-turn lanes at intersections without additional right-of-way requirements. Access to platforms may be limited to both ends of the station, or, if traffic is light, crosswalks to adjacent sidewalks can be provided along the length of the station.

6.5 TRAFFIC CONTROLS

Traffic signs, signals, pavement markings, and controls are essential complements to geometric design features. Detailed guidelines for their application are contained in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (*28*). Part 8 covers signs, illumination, and pavement markings for highway–light rail transit grade crossings. The following discussion summarizes and extends those guidelines. It covers general traffic controls, traffic signals, signing, and pavement markings. Related information for bus transit is contained in Chapter 5 of this guide.

6.5.1 General Traffic Controls

The application of parking, street routing, and turn controls should reflect roadway width and geometry, track configurations, and arrangements along the land uses that abut the roadways where LRT run. Following are some general guidelines.

- It is desirable to restrict parking along arterial roadways where traffic volumes are heavy and peak-hour congestion is common. Parking may be restricted all day or just in the peak hours.
- Curb parking must be restricted where LRT operates in curb lanes. However, cross-streets or rear-door access should be available to serve the commercial activities along the LRT line. Where this is not practical, the curbside track alignment should be re-evaluated.
- One-way streets are desirable to eliminate left-turn and head-on collisions and to improve traffic signal progression. From an LRT perspective, they permit center-running LRT with stations along a narrower roadway than would be required for two-way operations.
- Left turns by general traffic should be prohibited at busy intersections where it is not practical to provide left-turn lanes. Left turns generally should be prohibited along median running LRT in mixed traffic or in shared lanes. Left turns also should be prohibited along segregated median-running LRT where space is not available to provide protected signal-controlled, left-turn lanes.
- Right turns by general traffic should be prohibited at intersections with heavy pedestrian volumes, such as in the city center. Right turns may be prohibited where LRT operates in curb lanes in mixed traffic. They must be prohibited where LRT runs in reserved curbside LRT lanes unless a separate right-turn phase is provided for general traffic. This is necessary to avoid motor vehicles from the adjacent lane crossing the tracks to turn right.
- LRVs (and buses) sometimes can be exempted from turn restrictions that apply to the general flow. LRT running ways should be protected by stop signs or traffic signals at intersecting streets.
- The following guidelines apply to physically segregated, median-running LRT.
- The number of streets crossing the tracks should be kept to a minimum.
- Street crossing generally should be signalized.
- Left-turn lanes with protected signal phases should be provided for motor vehicles turning left. The left-turn phase should follow the phase for LRT and the through traffic.
- Pedestrians should be encouraged to use crosswalks at intersections. Mid-block crossings should be prohibited whenever possible where LRT operates in segregated median running ways (with attendant high speeds). Fencing along the edges of the tracks is desirable.

Figure 6-28 illustrates examples of pedestrian barriers installation at unsignalized mid-block crossings. These innovative "Z" and "N" crossing designs force the approaching pedestrians to look in the direction of oncoming trains when they cross the tracks.

6.5.2 Traffic Signals

This section provides guidelines for LRT signal displays and placement, signal sequences, and signal timing strategies.

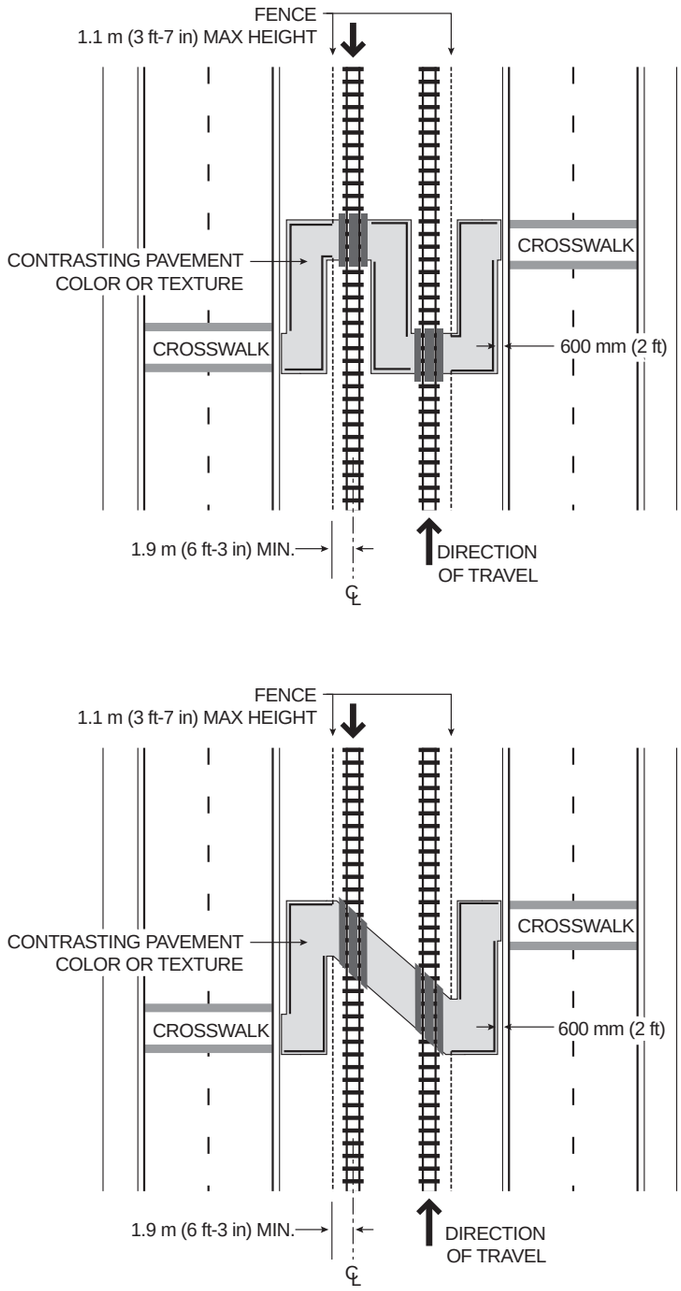
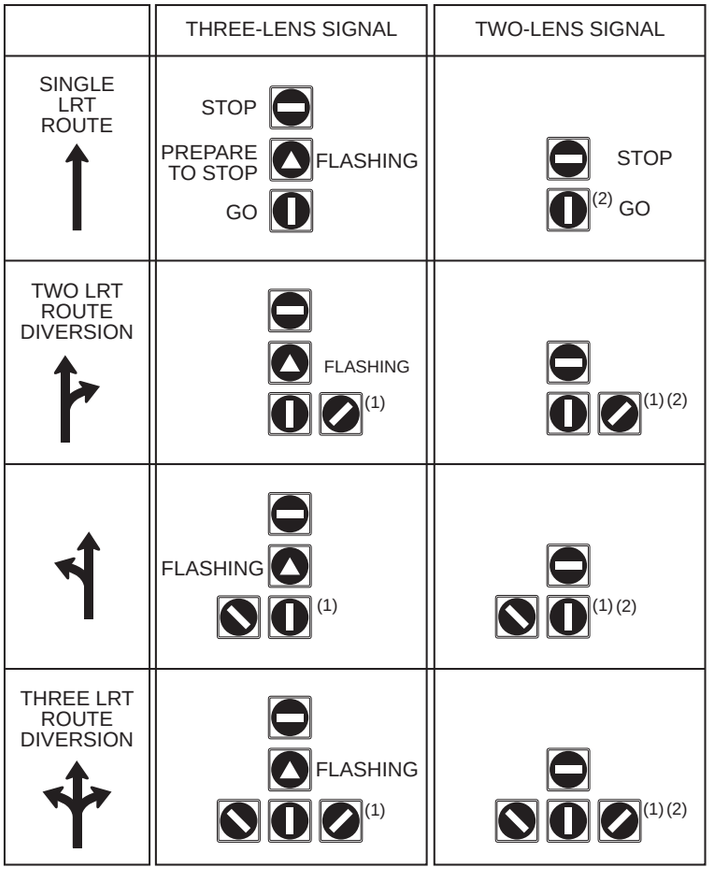


Figure 6-28. Mid-Block Side Platform Station in Median for LRT in Exclusive Right-of-Way (*27*)

Displays and Locations

The MUTCD suggests that light rail transit movements be controlled by special LRT traffic signal indications in semi-exclusive alignments (right-of-way Type B) at non-gated crossings. The special signals for use by rail operators (Figure 6-29) differ from typical traffic signals. The LRT signal displays may be desirable where LRT trains operate in shared or reserved (non-segregated) rights-of-way. In both cases, the clearance intervals for trains can be displayed before the normal three-to-five second clearance for motor vehicles. This practice will minimize the chances of trains backing up into cross-streets.



Notes:
All aspects (or original indications) are white.
(1) Could be in single housing.
(2) "Go" lens may be used in flashing mode to indicate "prepare to stop."

Figure 6-29. Example of LRT Signals (*27*)

Figure 6-30 depicts of signal displays, signing, and pavement markings for a typical median LRT design used in Dallas.

- The LRT signals are pedestal-mounted, and the main arterial signals are placed overhead. This separation reduces possible confusion resulting from motorists responding to light rail signals.
- Pole-mounted pedestrian signals give pedestrians ample clearance times to access both streets.
- Arrow displays control left turn movements, while green "balls" govern through movements. These displays enable the left turns to occur on protected phases.
- LRV-activated illuminated train crossing signs are sometimes placed in the roadway median to warn oncoming motorists of an approaching train. The signs are illuminated after detection by oncoming trains.

Phases and Sequences

The number of traffic signal phases should be kept to a minimum, and cycle lengths should be as short as possible. This is achievable at conventional intersections where left turns are prohibited on the street with the LRT.

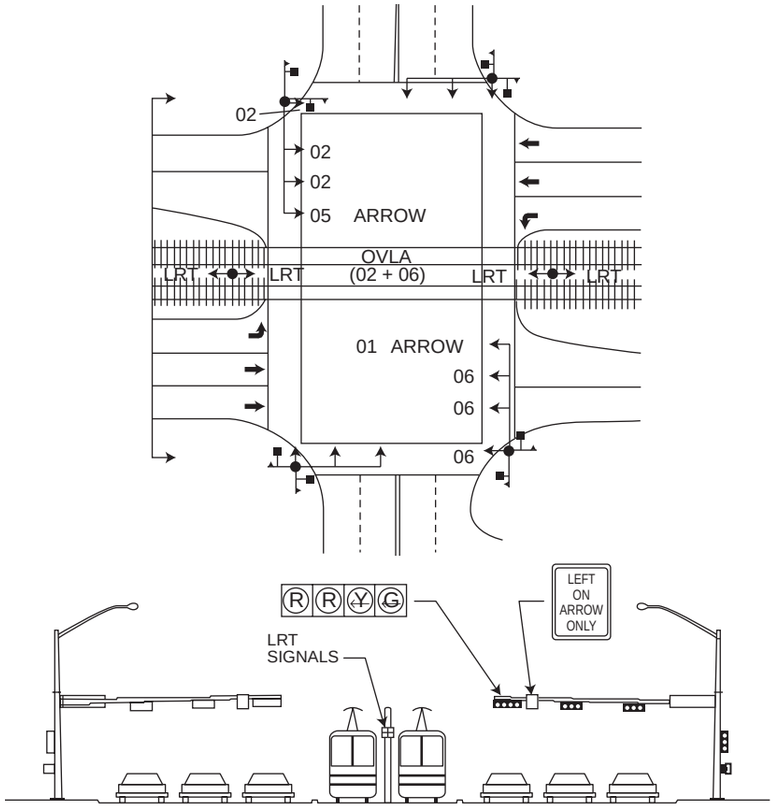


Figure 6-30. Example of Intersection Design for Median-Running LRT (*17*)

A special signal phase is needed to accommodate left turns alongside segregated tracks. The left-turn phase must follow the combined phase for through traffic and LRT. This phasing will minimize the likelihood of same-direction crashes between LRVs and left-turning motor vehicles—a major source of crashes in several cities. The following phasing is suggested:

- Arterial through-traffic, LRT and right turns;
- Arterial left turns; and
- Cross-street.

Special LRT phases should be provided where LRVs turn left or right from one street onto another, or onto a private right-of-way. This phase could be activated by LRVs and occur in established signal cycles.

Because of the wide streets associated with median-running LRT, the special required phase for left turns, and the need to give pedestrians ample time to cross the artery, long cycles (90 seconds or more) are usually needed.

Timing Strategies

Traffic signal timing along rail (and bus) routes should include both active and passive priorities.

- *Passive Signal Priorities.* These priorities are desirable along streets with high transit volumes. They allocate the green times based upon the number of people (per lane) moving on each approach through an intersection, rather than just the number of motor vehicles. They coordinate traffic signals along a

roadway based upon the average LRT vehicle speeds. A delayed pedestrian walk phase is one example of a passive signal priority. The advanced phase allows right-turning motor vehicles to complete their turns before the start of the pedestrian "Walk" phase. This will allow transit vehicles operating in lanes where right turns are permitted to travel through intersections without the delays caused by pedestrians crossing during the "Don't Walk" phase. The local agency's hierarchy of priorities among modes may dictate the applicability of this technique. In some places, pedestrians are given the first priority; thus, delaying the "Walk" phase may not be compatible with local transportation objectives.

- *Active Transit Signal Priorities.* Active signal priority treatments include both transit signal priorities and transit signal preemption. Both give transit vehicles preferences over the traffic. Both involve detecting the presence of a transit vehicle and depending upon the system logic, and the prevailing traffic conditions, give transit vehicles special treatment. Both must be able to detect the presence of an LRV (or bus) and to predict the vehicle's arrival time at an intersection.
  - Transit signal priorities give transit vehicles several seconds of additional green time either at the beginning or the end of a traffic signal phase by shortening the cross-street green time. They may be unconditional in that transit vehicles get additional green time whenever LRVs approach an intersection, or it may be conditional in that LRVs get additional green time *only* when they are late. However, the green time should not be advanced or extended in the same cycle.
  - Traffic signal technologies preempt normal traffic signal cycles at an intersection to facilitate the safe passage of fire and emergency vehicles. These technologies have been available to local jurisdictions for more than 20 years. Many jurisdictions have already installed both hard-wired and wireless technologies. Such systems can preempt signals for LRVs, but this is less common. One application involves transit vehicles turning left or right from a segregated median right-of-way. Transit-preempted (or activated) signals can give LRVs a special phase by lengthening the signal cycle or by taking time from other phases.
- *Implementation Guidelines.* The various transit signal priority treatments should be implemented as a cooperative effort of the public agencies that are responsible for streets, traffic, transit, and emergency services. Conflicts should be resolved and consensus among jurisdictions and agencies should be achieved. Following are suggested guidelines and considerations.
  - The system should improve schedule adherence.
  - The system should improve LRT operating efficiency, reduce operating cost, and allow greater schedule flexibility.
  - The priority system should be part of a larger ITS program that includes improved rider information and other services.
  - The system should reduce overall person-delay without creating large increases in cross-street delay.
  - Vendor marketing is often an important factor in creating a local impetus to pursue preemption and priority strategies. Practitioners should ensure that the preemption devices and priority strategies will solve the problems that they face.
  - The need, justification, and design of transit priority signal systems is a complex, corridor-specific or jurisdiction-specific mix of policy, technology, and public perception factors. Priority must

be assessed on technical merit and ability to address identified problems. If a local jurisdiction's objective is to move people rather than just vehicles, transit preemption and transit priority are practical means to that objective, when applied well.

Signals for Side-Running LRT

Special signing, signal displays, markings, and phasing are essential where side-running LRT intersects major arterials (see Figure 6-31). The physical designs of the LRT crossing and roadway intersection are carefully integrated to provide safe operation.

- The motor-vehicle stop bar for the cross-street is located on the near side of the tracks along with "Stop Here on Red" sign to discourage motor vehicles from queuing on the tracks. A track clearance phase is used in conjunction with preemption to ensure that the tracks are clear before the LRV arrives.
- A fiber optic sign with a "No Right Turn" symbol (R3-1) is illuminated by the approach of the LRV for the turning movement parallel to the tracks. This sign provides information to the motorist traveling parallel to the tracks to avoid turning into the lowered gates.
- The placement of the railroad gates, cantilever rail signals, and the traffic signals is designed to provide good visibility and a clear message to motorists. The traffic signal pole is placed in front and slightly to the right of the railroad gate structure. The traffic signal heads are set at the minimum elevation, allowed by the MUTCD, to ensure that they do not obstruct the view of rail signals that are located behind and above the traffic signal.

Signal phasing can be complex where trains pass through an intersection. Right and left turns onto the tracks are prohibited, and the artery green movement is continued. After the LRT has cleared, there may be a recovery phase for the stopped street traffic before the normal phasing occurs.

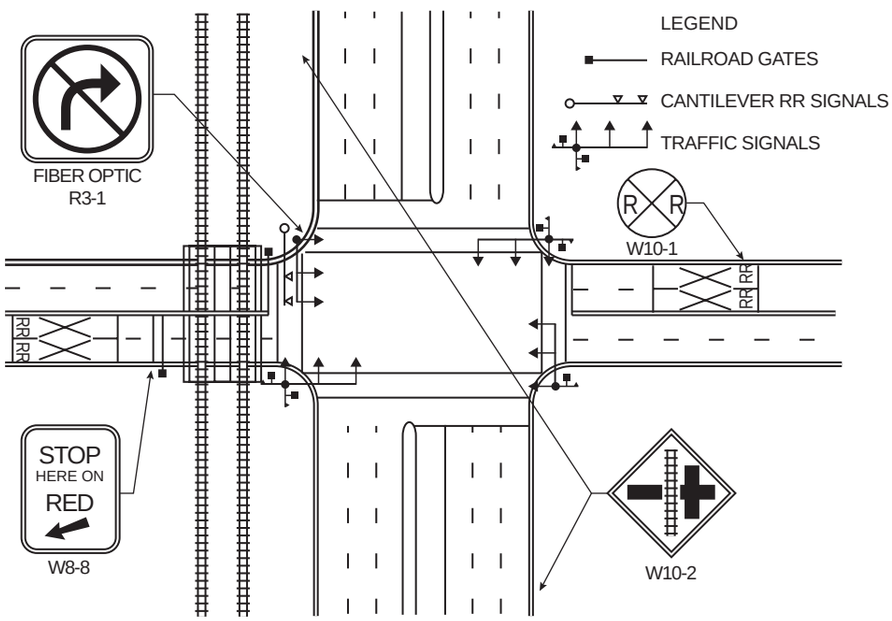


Figure 6-31. Example of Intersection Design for Side-Running LRT (*17*)

6.5.3 Signing and Pavement Markings

This section outlines the signing and pavement markings in the MUTCD relating to LRT facilities in streets. Supplementary discussions are included regarding signing requirements on crossing streets and for turn lanes, different approaches (colored pavement), and marketing ("branding" by way of symbols and logos).

Signing

Figure 6-32 shows examples of regulated signs for use along LRT lanes in roadway environments. Figure 6-33 shows examples of warning signs used for side-running running ways and other types of off-street, semi-exclusive or exclusive rights-of-way.

Many of the signs and pavement markings used to direct motor vehicle traffic away from bus lanes are used to maintain the exclusivity of LRT rights-of-way and shared bus-rail facilities. For example, the

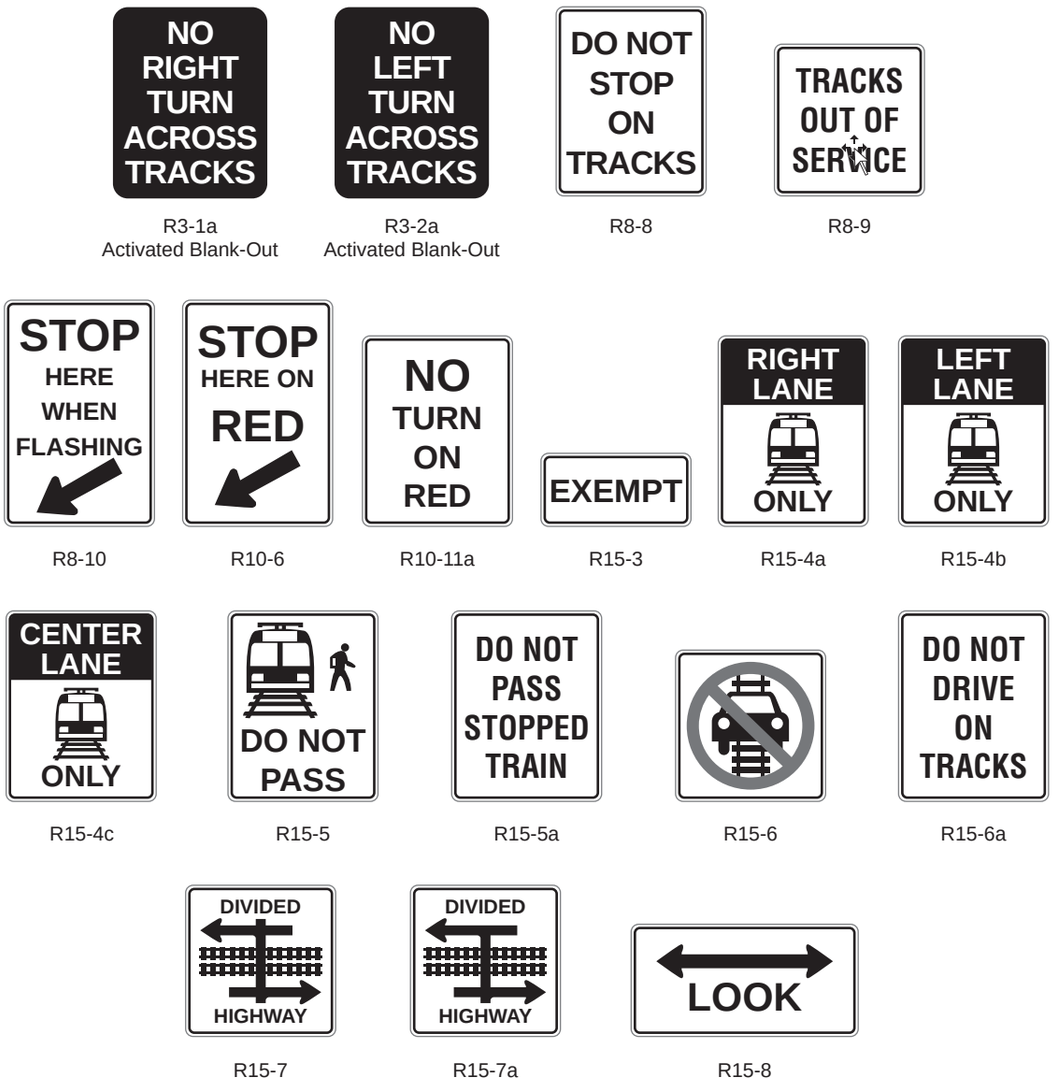


Figure 6-32. LRT Regulatory Signs (*27*)

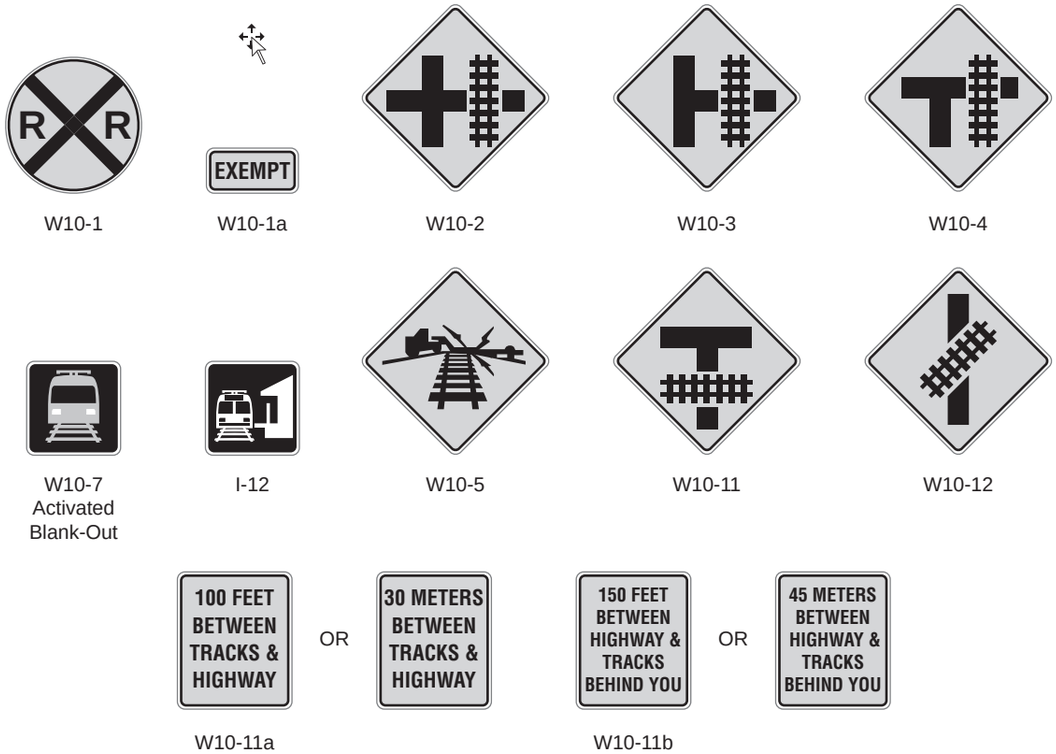


Figure 6-33. Warning Signs and LRT Station Signs (*27*)

reader's attention is directed to signs R15-6 and R15-6a to keep motor vehicle traffic off LRT tracks, and signs R15-7 and R15-7a to warn motorists of opposing traffic patterns on opposite sides of independent LRT tracks. Similarly, signs W10-2, -3, -4, -11, and -12 offer various illustrations of roadway–railroad intersection configurations where the LRT tracks are distinguished from roadways.

The MUTCD is designed for use on roadways and highways. It does not address many rail-only situations. For uniformity and consistency, many transit-operating agencies adopt uniform signing for all parts of their respective LRT system, including sections near roadways and independent rail rights-of-way. This means MUTCD standards and signing often are used in rail-only segments of LRT systems.

Pavement Markings, Colors, and Branding

The MUTCD provides guidance for pavement markings to accommodate the dynamic envelopes of transit vehicles. Figure 6-34 illustrates suggested treatments along tangent sections of track. Figure 6-35 illustrates examples of using pavement markings and contrasting pavement colors and textures along curved sections of track. The actual dimensions should be LRV-specific.

Some cities have found success using contrasting colored pavement to indicate areas reserved for transit vehicles. Colored pavement can be very helpful in identifying the area affected by the LRV's overhang or by its dynamic envelope. Distinguishing this area with a contrasting color tells pedestrians and motor vehicle operators the areas they must avoid.

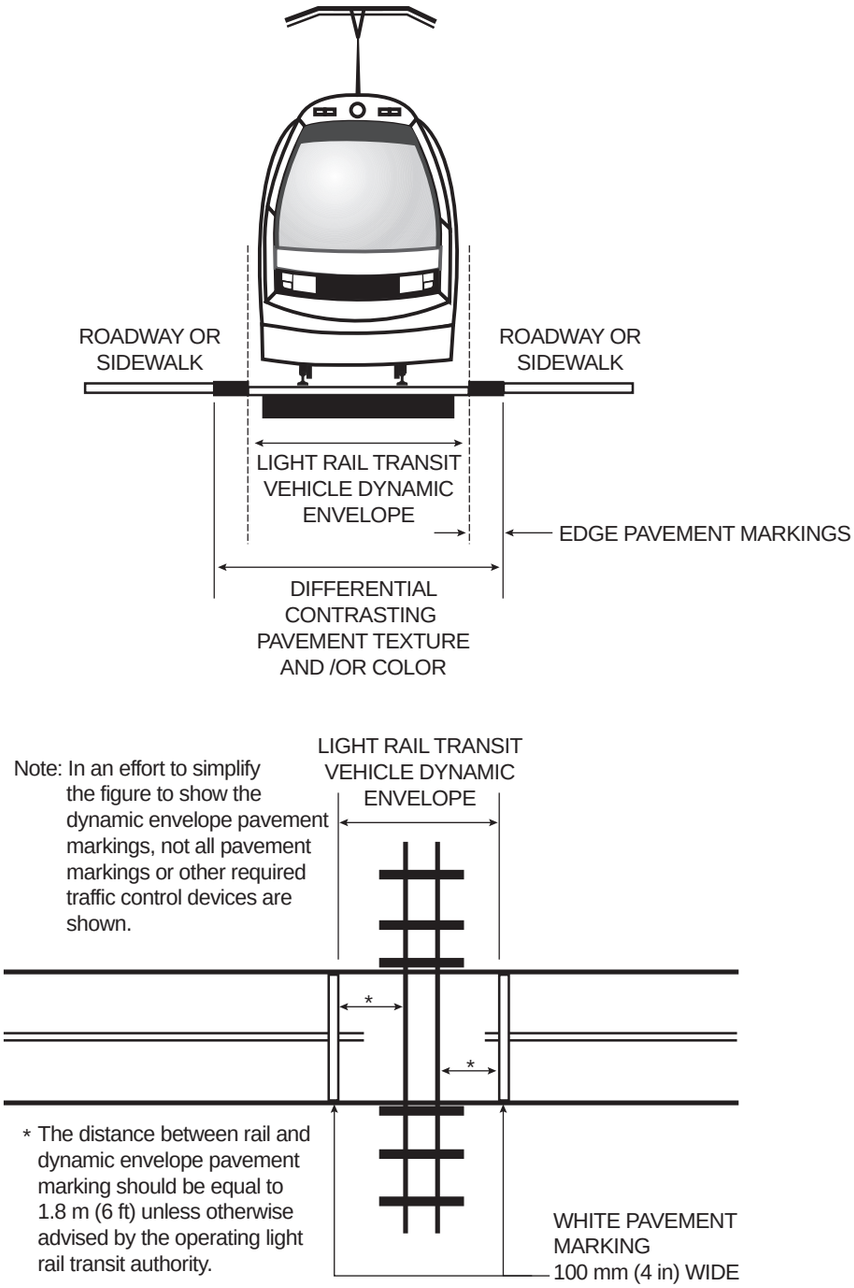


Figure 6-34. LRT Transit Vehicle Dynamic Envelope (*27*)

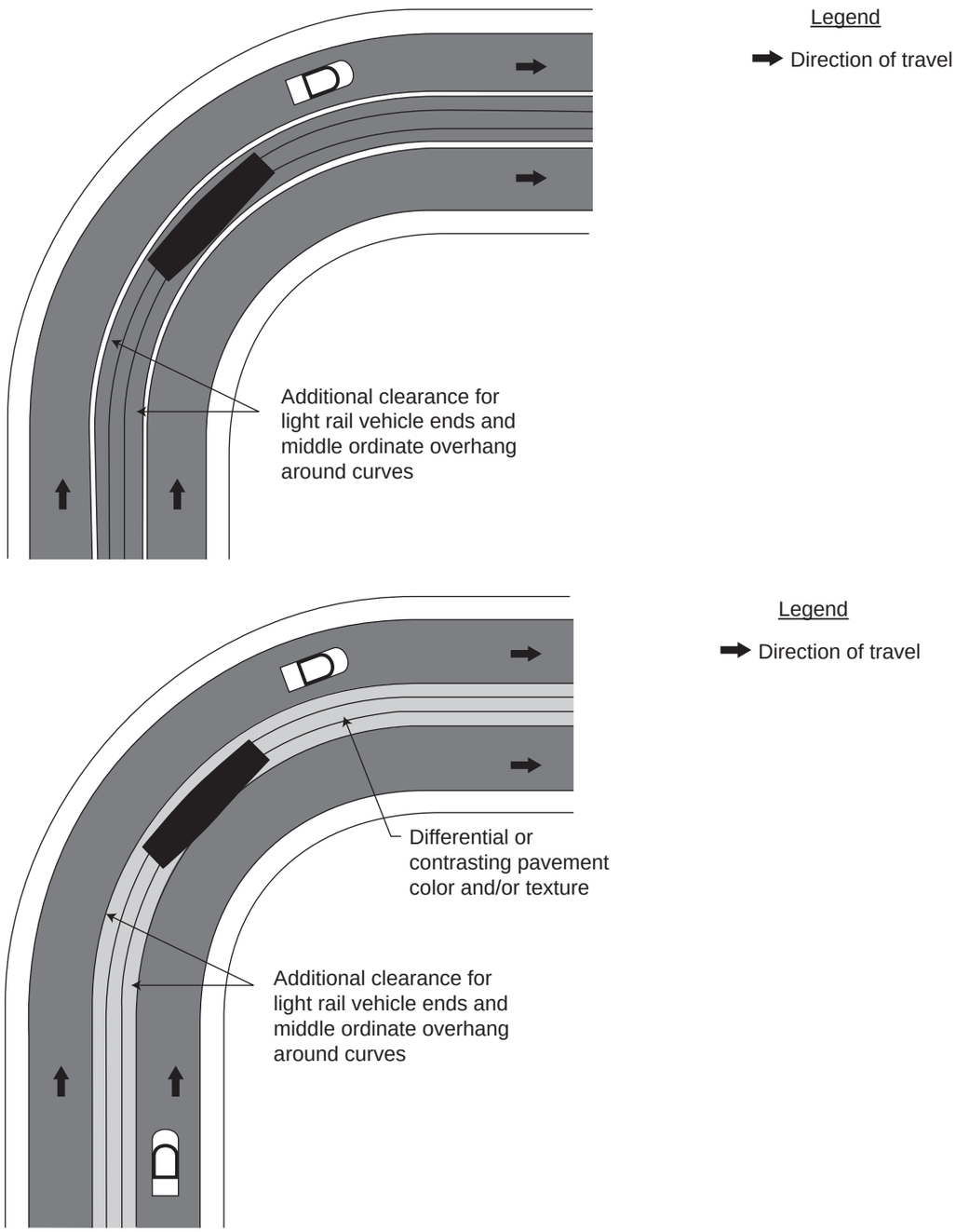


Figure 6-35. Example of LRT Vehicle Dynamic Envelope Pavement Markings (*27*)

Many transit agencies have coordinated with local street and highway departments to present a constant image or symbol for the transit system so pedestrians, drivers, and others can associate transit service with the roadside markers or pavement markings. A common logo, such as the bold "**T**" in Boston, the bold "**M**" in Los Angeles and Washington, or the trefoil of three circles in Miami, creates a "brand" or public image that is regionally recognizable. Other approaches to branding are the use of iconic colors associated with the rail, as in New Jersey, or with a distinctive shape or outline surrounding the bold initial. These and numerous other unifying symbols or logos brand the transit service, identify it in traffic situations, and convey information with little verbiage.

6.6 LRT/BUS LANE ENFORCEMENT

This section describes the physical, signing, and operational measures used to maintain exclusive LRT use of the lane. These are similar to the measures described for exclusive bus facilities in Chapter 5.

Where special facilities are built to promote improved transit operations, lane enforcement helps ensure the effective operational benefits of the transit investment. Effective enforcement policies should be coordinated among transit and public safety agencies within a jurisdiction for operations and traffic enforcement, such as removing illegally parked or disabled motor vehicles from lanes. Facility design, begun during the planning stage and continued throughout development into operation, provides a passive enforcement of optimum operations of a transit facility. Striping, signing, and barriers are the most common design features that enforce vehicle restrictions in transit facilities.

Median transit (busway, streetcar, or LRT) operation (Type B right-of-way) provides low-conflict movement for transit and avoids demands by other motor vehicles for use of active travel lanes. A median facility developed as a high-standard dedicated transit line, implies use by streetcars or LRVs with specific stops adhering to high average speeds. Depending on local travel needs, a median rail transit line may be supplemented with a local bus transit service operating in the right general-purpose lane. With minimal design, other vehicles can be kept off transit medians with bollards, flexible posts, or raised curbs. Curb arrangements must accommodate the bottom of the rail vehicle as it passes.

When a rail transit vehicle transitions from in-street operations to a more exclusive right-of-way, signing and designs should prevent general traffic from following the streetcar or LRV into the median or reserved transit lane.

There are several methods for providing an appearance of physical separation between general-purpose lanes and pavement reserved for LRVs or streetcars. These include rumble strips to roll-over curbs, medians, and concrete barriers. The type of separation provided can affect the cost of the facility, width of the median facility, the ability to conduct maintenance operations, and the overall effectiveness of the facility. Facilities used exclusively by rail may have more significant barriers than those that must accommodate buses.

- A rollover curb is well suited to allowing buses to bypass a rail vehicle or a disabled bus. However, since the curb does not preclude entry by non-transit vehicles, it poses some risk of illegal use.
- A raised median would prevent general traffic from crossing or entering the transit lane, but this also forms a barrier for emergency vehicles, potentially increasing their response time. In areas with high pedestrian traffic and infrequent signalized crossings, the potential exists for a high number of pedestrian mid-block crossings of the roadway.

- Where snow clearance is required, half-globe barriers or flexible posts may interfere with plowing operations.
- In some places, a combination of a rollover curb design, effective signing, and a strict enforcement policy can keep general traffic out of transit lanes and not preclude the safe passage of emergency vehicles.
- High fines for illegal parking on LRT track and prompt towing of errant motor vehicles are supportive practices.

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7 Pedestrian and Bicycle Access

In This Chapter:

Transit planning and design should not end at the stop or station, but extend into the surrounding community. Riders must be able to reach bus stops or train stations comfortably, safely, and by the most direct routes. Access to stops and stations can be gained by walking, bicycle, motor vehicle, and bus.

Walking from adjacent land uses requires stops and stations to have safe, direct, and accessible pedestrian connections to the adjacent community. Cycling from the surrounding community requires stops and stations to be connected to appropriate bicycle facilities, and to have ample and secure bicycle parking.

This chapter outlines planning and design guidelines that achieve these objectives. It also contains some general guidelines for passenger amenities at stations and stops.

7.1 PEDESTRIAN ACCESS

Pedestrian access plans should cover the catchment areas around each stop of local and express transit services that are about 400 m (0.25 mi) and 1,200 m (0.75 mi), respectively. Designs should consider walkway width, safety and lighting, wayfinding or signage, and connections to major activities. Facilities design should also consider long-term operations and concerns including choice of durable and climate appropriate materials, and designs that either minimize or facilitate ongoing maintenance such as restriping or snow clearance.

Tables 7-1 through 7-3 provide general guidelines for improving the walking environment in terms of accessibility, activity, and amenity.

Table 7-4 is a guide for various types of pedestrian improvements that practitioners should consider in the planning and design process. For each design issue, the table indicates the applicable facility for the types of improvements.

Table 7-1. Methods to Improve the Walking Environment for Accessibility

1. Traffic Controls	
1- 1	Provide traffic signals with pedestrian crossing indications.
1- 2	Place traffic signals where pedestrians can see them and easily access pedestrian push buttons.
1- 3	Avoid long traffic signal cycles to reduce pedestrian waiting times.
1-4	Limit use of exclusive "walk" phases ("Scramble System") where it causes unreasonable vehicle delay.
1-5	Clearly mark crosswalks (Use longitudinal and transverse markings).
1-6	Use barriers or fences to prevent unsafe crossings.
1-7	Eliminate or signalize multi-lane roundabouts in cities.
1-8	Illuminate intersections.
1-9	Prohibit or control left or right turns across heavily used crosswalks.
1-10	Limit the number and spacing of curb cuts along sidewalks.
1-11	Consolidate driveways wherever possible.
1-12	Eliminate parking lot or garage driveways along principal shopping streets.
1-13	Avoid large curb radii in built-up areas.
1-14	Construct curbs to separate cars from pedestrians.
1-15	Enforce pedestrian right-of-way rules.
2. Sidewalk Improvements	
2-1	Keep street corners clear of obstructions such as streetlight and traffic signal poles.
2-2	Remove obstacles from sidewalks, especially along building fronts.
2-3	Construct arcades at intersections with heavy pedestrian volumes.
2-4	Prioritize improving non-ADA compliant curb ramps near and connecting to transit stops.
2-5	Widen sidewalks.
2-6	Provide buffer area between the sidewalk and the adjacent street.
2-7	Provide pedestrian refuge islands.
2-8	Locate bus stops adjacent to offices, schools, and shops (i.e., on same side of street, wherever possible).
2-9	Provide adequate sidewalk illumination.
3. Pedestrian Facilities	
3-1	Vertically separate pedestrian and vehicle traffic.
3-2	Use skyways to connect parking garages and transit stations with shops and offices.
3-3	Link subway stations to buildings with underground concourses and arcades.
3-4	Provide mid-block pedestrianways, paths, and plazas.
3-6	Provide accessible sidewalk ramps with detectable warnings, at all pedestrian crossings.
4. Traffic Restraints	
4-1	Provide "bulb-outs" or street "neckdowns."
4-2	Provide transit and pedestrian streets where warranted by land use.
4-3	Create pedestrian precints where warranted by development density, pedestrian demands, and street patterns.
4-4	Reduce local street motor vehicle continuity in residential areas by installing diverters or cul-de-sacs with bicycling and walking path connections.
4-5	Other traffic-calming techniques.

Table 7-2. Methods to Improve the Walking Environment for Activity

1. Types of Activity	
1-1	Encourage mixed-use developments in commercial centers.
1-2	Require residential units on upper floors of new office buildings.
1-3	Require ground-floor retail space in new office buildings and parking garages.
1-4	Encourage small shops that provide evening activity such as book stores and cafes.
1-5	Avoid "blank walls" along downtown streets.
1-6	Eliminate drive-in businesses along main shopping streets.
1-7	Increase development in commercial centers.
2. Activity En-Route	
2-1	Provide areas where people can meet, see, or be seen, (i.e., people-watching places).
2-2	Create temporary "mini-parks" on vacant land in downtown areas.
2-3	Provide activities along sidewalks, skyways, and concourses.
2-4	Obtain variety and interest through the placement and design of activities and amenities.
2-5	Stimulate the senses along the walkway system (i.e., sight, sound, and smell).
2-6	Provide pedestrian–transit information centers.
3. Street Life	
3-1	Control sidewalk vendors.
3-2	Provide programmed activities around the year.
3-3	Create merchants' or community association to promote events and to help maintain improvements.

Table 7-3. Methods to Improve the Walking Environment with Amenities

1. Views and Focal Points	
1-1	Give pedestrians a sense of orientation and place.
1-2	Provide interesting vistas and focal points that take advantage of natural vistas and views wherever possible.
1-3	Keep viewing distances short.
1-4	Recapture and redesign waterfronts for pedestrians.
1-5	Avoid transportation facilities or buildings that create "Chinese Walls," and avoid "fortresses" and "plazas in the sky."
1-6	Conserve historic areas—especially where buildings are also architecturally significant.
1-7	Avoid large barren plazas of more than 225 m^2 (2,500 ft^2).
1-8	Cluster buildings in suburban developments to make walking more attractive.
2. Streetscape Design	
2-1	Construct canopies to protect people from sun and rain.
2-2	Provide climate controlled skyways, concourses, and development complexes.
2-3	Design and place shelters, benches, fountains, and trash receptacles for convenient use.
2-4	Use lighting, landscaping, street furniture, and pavement texture to define pedestrian paths.
2-5	Use water in motion to create "variety and interest."
2-6	Use planting strips to screen parking areas from pedestrian ways.
2-7	Provide clear and coherent signing and graphics.
2-8	Develop design themes that reflect each community's character and heritage.
2-9	Prohibit overhanging street signs.
2-10	Create controlled design districts.

Source: Levinson, H. S. *Improving the Walking Environment*. Proceedings: Fifth Annual Pedestrian Conference, 1984.

Table 7-4. Pedestrian Improvements Guide

			Facility Location Type			
Topic	**Issue/Opportunity**	**Questions**	**CBD**	**Urban**	**Suburban**	**Rural**
Reduce Walking Distance	Provide shortcuts to reduce the distance pedestrians must walk	Near a transit facility, are there any opportunities to provide pedestrian shortcuts to reduce walking distance?		✓	✓	
	Match crossing opportunities to pedestrian desire lines	Do crossing opportunities near the transit facility match likely pedestrian "desire lines" for crossing? If not, can one be provided?	✓	✓	✓	✓
	Provide continuous sidewalks (or paths) wide enough for two people	Does the transit facility have continuous sidewalks, at least 1.5-m (5-ft) wide, leading to it? Can a wider sidewalk be provided?	✓	✓	✓	✓
Provide Pedestrian-Sensitive Traffic Controls	Install traffic signals	Do the signals provide enough time for elderly and children to cross each street?	✓	✓	✓	✓
		Are the signal displays easy for pedestrians to see?	✓	✓	✓	✓
		Are pedestrian signals provided across wide streets or where pedestrian volumes are heavy?	✓	✓	✓	✓
		Are there major conflicts between pedestrians and turning traffic?	✓	✓	✓	✓
		Are walk lights installed near transit stops?	✓	✓	✓	✓
	Install median islands	Are center islands provided along wide streets (where there are four or more lanes) or at main pedestrian crossings?	✓	✓	✓	✓
Address Special Population Needs	Consider people carrying items (e.g., luggage, groceries, etc.)	Does the transit stop avoid circuitous routes, particularly in areas where pedestrians may be carrying bulky items (e.g., shopping areas or airports)?	✓	✓	✓	✓
	Recognize special needs of elderly/ disabled	Is there a continuous, unobstructed path to the bus stop that can be negotiated by a person using a wheelchair and that is also usable by persons with other disabilities?	✓	✓	✓	✓
	Recognize special needs of schoolchildren	Do school children use the bus stop? If so, will sidewalks or walkways (including crossings) that clearly define the route ensure the safest trip for schoolchildren? Does the route have any visual obstacles that might make it difficult for motorists to see children (e.g., high fences or overgrown hedges)?	✓	✓	✓	✓
Improve Street Crossing Safety/ Convenience	Calm traffic along streets	If a bus stop is on a street with high-traffic volumes and speed, can traffic calming measures be implemented?		✓	✓	✓
	Traffic Control Devices	Consider additional signing and pavement marking.	✓	✓	✓	✓

Table 7-4. Pedestrian Improvements Guide (*continued*)

	Narrowing of streets (fewer traffic lanes for pedestrians to cross)	Is it possible to reduce the number of traffic lanes on the facility and not significantly impact traffic flow or transit operations? If it is not possible to narrow the street, is there a way to locate the bus stops on a narrow street? Or, is there a way to narrow the perceived width with vertical elements such as trees, street lights, or parked cars?	✓	✓	✓	✓
	Extend curb, at street corners/ tighter curb radii	Can either curb extensions or tighter curb radii be provided in the corridor to provide safer crossings for pedestrians without negatively impacting transit operations?	✓	✓	✓	✓
	Increase crosswalk visibility	Is budget available to include special paving in crosswalks? If so, have construction and maintenance costs been considered in the selection of crosswalk treatments?	✓	✓	✓	✓
	Locate bus stops to discourage crossing streets at undesirable locations	Are the transit stops at or near a convenient and safe crossing? Are there major pedestrian generators (such as a school, shopping center, or office building) across the street with no way for pedestrians to access them?	✓	✓	✓	✓
	Grade separation	Could pedestrian access be provided with at-grade crossings where feasible? If not, will a grade-separated crossing serve people other than transit riders?		✓	✓	✓
Other Safety Treatments	Screen surface parking	Does the bus stop have surface parking nearby? If so, can it be screened?	✓	✓	✓	
	Natural urban surveillance near transit stops	Does the bus stop have natural surveillance nearby (e.g., a park, playground, or residential or commercial buildings with windows facing the bus stop)? If not, can it be located at an area with more natural surveillance?	✓	✓	✓	
	Light pedestrian routes	Are pedestrian routes near the transit facility adequately illuminated? If not, can lighting be provided?	✓	✓	✓	✓
	Provide weather protections (keeping sidewalks clear of snow, etc.)	Does the transit facility provide weather protections? If not, can weather protection be provided?	✓	✓	✓	✓
Enhance Streetscape	Increase tree plantings, and buffering from traffic	Does the pedestrian access route provide a buffer for pedestrians from vehicles? At a minimum, sidewalks and vertical curbs should be provided for the pedestrian.	✓	✓	✓	✓
	Provide street walls (e.g., welcoming storefronts)	Is there roadway access the bus stop that includes street walls? Can enhancements be made to the streetscape to improve the street walls of the street?	✓	✓	✓	
	Provide functional street furniture	Are there physical obstructions along the pedestrian route? If so, can they be moved to provide a safe and well-defined pedestrian environment?	✓	✓	✓	✓
	Install coherent, small-scale signage	Does the pedestrian link include coherent, small-scale signage appropriate to a pedestrian (versus vehicle)? Do the transit signs provide coherent information to both the novice and experienced transit user?	✓	✓	✓	✓

7.1.1 Reduce Walk Distance

Provide Shortcuts

Where sidewalks do not provide direct connection to a destination, people tend to take shortcuts. For example, cul-de-sacs are effective in restricting automobile through traffic, but they can restrict pedestrian mobility unless public paths are provided to connect the cul-de-sac with adjacent streets (Figure 7-1).

Streets with numerous connections to other streets, such as those in a grid network, offer the pedestrian a more direct route than streets with cul-de-sacs, dead ends, long blocks, or circular patterns. However, shortcuts or paths can be provided to reduce walking distance, where street patterns are discontinuous.

Match Crossing Opportunities to Pedestrian Desire Lines

Whenever possible, crosswalks should be positioned along preferred pedestrian routes, or "desire lines." This will minimize the number of people who will cross in unsafe locations. At bus stops, the nearest crosswalk should match pedestrian desire lines, whenever possible (Figure 7-2).

- In new developments, local governments should require that cul-de-sacs and dead-end streets include pathways to other streets.
- Where informal paths are found, it may be desirable to pave or maintain them.
- Constructed paths should be ADA accessible.

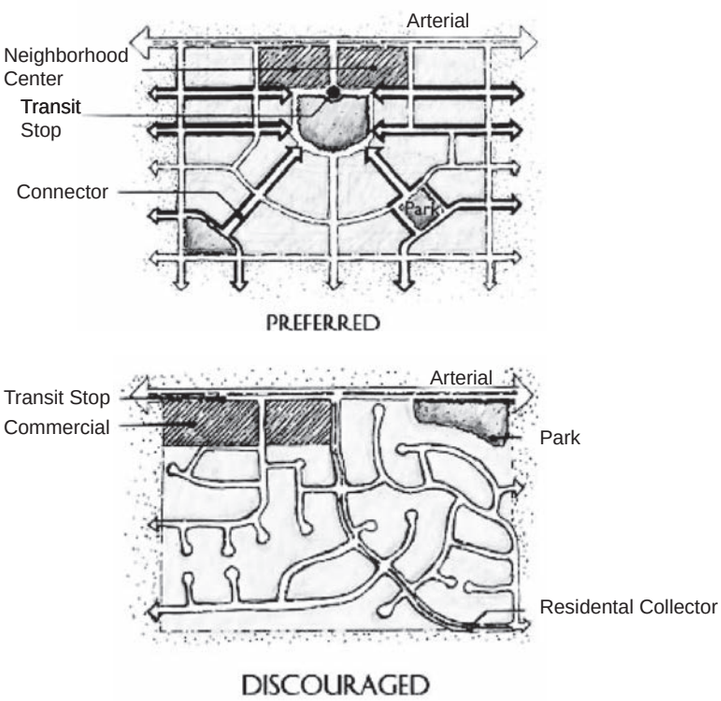


Figure 7-1. Shortcuts to Access Transit (*15*)

Figure 7-2. Pedestrian Crossing That Matches Desire Lines (*14*)

Provide Continuous Sidewalks (or Paths)

The presence or absence of sidewalks influences a person's decision about whether to walk from one place to another, take the bus, or drive. Sidewalks provide a separate, all-weather hard surface walkway along streets and roads for pedestrians. They contribute to safety by separating pedestrians from vehicles, the separation is especially important on higher volume arterials and streets near schools or other facilities that generate large numbers of pedestrians. In the absence of sidewalks, people may be forced to walk in the street or along the shoulder, close to moving traffic—a condition that can be dangerous and intimidating.

Some neighborhoods have sidewalks that are not continuous, in front of some buildings or homes but not in front of others (Figure 7-3). Sidewalks may be on one side of the street but not on both sides. For many pedestrians, it is difficult or impossible to walk through the areas where sidewalks are missing since the paths are blocked, muddy, or otherwise hard to traverse. People who are in wheelchairs or have vision impairments may find it impossible to walk under these conditions.

Therefore, continuity of sidewalks should be improved by filling in gaps in the existing sidewalk system. Figure 7-4 shows how sidewalks can be designed to avoid obstructions.

- The Institute of Transportation Engineers (ITE) guidelines recommend a minimum width of 1.5 m (5 ft) for a two-way sidewalk.
- Ideally sidewalks should be continuous along both sides of a street.
- Sidewalks should be separated from traffic.
- Sidewalks should be diverted around obstacles where necessary, but should avoid unnecessary meandering.

Figure 7-3. Sidewalk That Ends Abruptly (*14*)

Figure 7-4. Sidewalk Design to Avoid Obstructions (*14*)

7.1.2 Provide Pedestrian–Sensitive Traffic Controls

Install Traffic Signals

Traffic signals should be installed at locations where heavily used roadways cross, where pedestrian movements are heavy, and at access points to schools, hospitals, and major developments. The signals should be clearly visible to both motorists and pedestrians and timed to reflect the needs of both groups.

Additional pedestal or pole-mounted traffic signals may be desirable to improve pedestrian visibility, and to improve visibility for motorists when overhead signals are obscured by sunlight. The supplemental far-side signal should be mounted 2.1 to 3.0 m (7 to 10 ft) above the pavement surface.

Special pedestrian signal indicators generally should be provided where (1) there are heavy pedestrian crossing volumes; (2) at mid-block locations where pedestrian volumes meet the warrants established in the *Manual of Uniform Traffic Control Devices;* (3) across roadways with six or more moving lanes; and (4) there are heavy left- and right-turning movements.

Walk indications generally should operate concurrently with the traffic in the same direction. Where there are major conflicts between pedestrian and turning vehicles, special pedestrian phases may be desirable.

Crosswalks should be installed at signalized intersections and signalized or unsignalized mid-block locations to guide pedestrians to cross at the designated locations. "Walk" times should be long enough to enable children and elderly people to cross the entire street safely. Where pedestrian indicators are provided, the use of "countdown" signals that show how much time remains will soon be required at all pedestrian signal locations.

Install Center (Median) Islands

Center (median) islands should be considered where there are four or more lanes. They may also be placed along two and four-lane streets. The islands should be wide enough to provide space for signs, signal poles, and a pedestrian area. Minimum width should be 1.5 to 1.8 m (5 to 6 ft). Walk islands are desirable where space permits. In some cases, it may be desirable to narrow travel lanes slightly, [e.g., from 3.6 to 3.0 m (12 to 10 ft)] to provide wider islands. For more guidance on when to use raised medians or islands, see *Safety Effects of Marked and Unmarked Crosswalks at Uncontrolled Locations.*

7.1.3 Special Population Needs

Consider People Carrying Items

Pedestrians traveling to and from a bus stop can carry bulky items such as luggage, groceries, etc. In certain areas, transit users usually carry these types of items (e.g., airports, shopping areas). Providing direct routes to transit stops is desirable to support ridership, particularly where transit users are more likely to be carrying bulky items.

Recognize Special Needs for Elderly/Disabled

Pedestrians often face obstacles in the environment. The needs of elderly and disabled pedestrians can vary, depending on their limitations and/or disabilities. Disabilities can range from physical conditions to

emotional illness and learning disabilities. Elderly pedestrians generally travel at slower speeds and often have disabilities. Aids for older pedestrians include:

- Traffic calming;
- Reduced roadway crossing distances;
- Traffic signals within 1.8 m (6 ft) of viewing distance;
- Refuge areas in roadway crossings;
- Shelter and shade;
- Handrails;
- Smooth surfaces and unobstructed travel ways;
- Signal timing at lower than average walking speeds; and
- Avoiding stairs, serious inclines, uneven surfaces, discontinuous paths, and obstacles such as disorganized street furniture, newspaper boxes, bike racks, etc.

Additional aids for pedestrians with disabilities include:

- Curb cuts (two curb cuts per corner—a level landing with no lip between sidewalk and road is the best design);
- Ramps (a level landing for stopping or turning is the optimal design);
- Wide walkways at least 1.5 to1.8 m (5 to 6 ft) wide are preferred; consider less only in restricted circumstances;
- Tactile warnings;
- Easy-to-reach activation buttons;
- Audible warnings and message systems;
- Raised and Braille letters for communication; and
- Maximum grade of 1:20 and cross slope of 1:50 (ramps can be 1:12).

Figure 7-5 shows an example of the types of sidewalk obstructions to avoid. Figure 7-6 illustrates an accessible design for pedestrians.

Recognizing Special Needs of School Children

In some communities, school children use public transportation to travel between school and home. Children should be able to travel safely to and from bus stops. Because children are typically smaller in size, it is more difficult for drivers to see them. Obstructions such as utility poles, parked cars, and vegetation can make it even more difficult for drivers to see children in the street environment. Children's behavior is often unpredictable, and they can have more physical limitations than adults, e.g., special sight limitations, slower response times, etc.). Given these factors, transit operators should pay special

Figure 7-5. Sidewalk Design to Avoid (*14*)

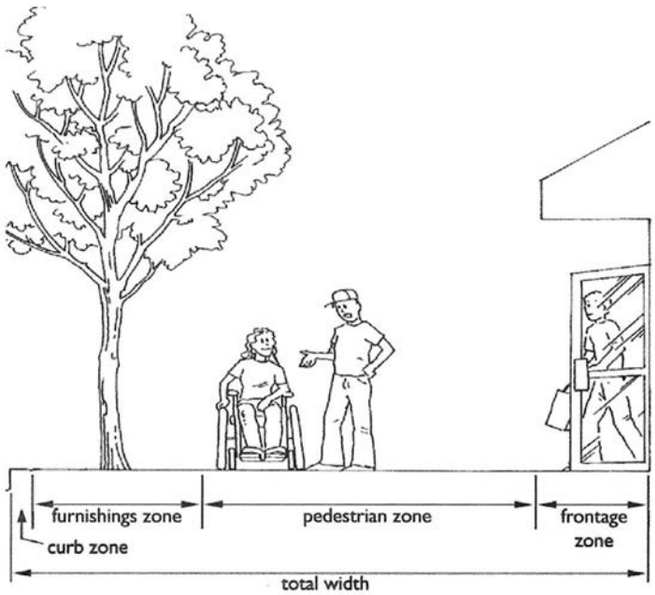


Figure 7-6. Schematic of Accessible Design (*12*)

attention to the pedestrian access routes that school children use. Special crosswalk delineation, approach road signing (including flashing school zone and reduce speed signals), and removal of any obstructions are desirable.

7.1.4 Improve Street Crossing Safety and Convenience

Streets and roads serve many diverse, sometimes competing functions. They provide channels for movement and also serve adjacent developments. Their design and operation should permit the safe and efficient movement of motor vehicles, buses, cyclists, and pedestrians. Congestion should be kept to a minimum, and excessive speeds should be discouraged. Conflicts should be avoided or eliminated.

From a pedestrian's perspective, there are selective opportunities for better balancing street space between vehicles and pedestrians, and "calming" traffic by reducing the number and width of lanes, and providing bulb-outs at intersections and tightening curb radii.

Calm Traffic

Traffic calming uses various techniques to slow traffic, reduce volumes, and alleviate other traffic-related impacts. Successful traffic-calming techniques (such as roundabouts) can influence motorist behavior [physical, psychological, visual, social, and legal (regulatory and enforcement)]. They can enhance the pedestrian walking experience and create a safer environment.

However, traffic-calming techniques should be carefully and selectively employed. Busy main thoroughfares and bus routes may not be candidates for all these measures. In some cases, the adverse effects on traffic and transit operations can outweigh the possible safety benefits resulting from traffic-calming actions.

Narrow Streets (Fewer Lanes for Pedestrians to Cross)

An effective method of improving pedestrian safety is to construct narrow streets with narrower and fewer lanes or to reconfigure existing wide streets to become narrower. Narrower streets are generally more pedestrian friendly than wide streets, and may have higher pedestrian volumes (*FDOT Pedestrian and Transit-Friendly Design,* p. 9). When a four-lane street is narrowed to three lanes, room is created for islands that can serve as refuges for pedestrians crossing the street. When left-turn lanes are provided at intersections, street capacity losses are minimal (Figure 7-7). This type of treatment should not be implemented where it would adversely impact major transit or traffic movements.

Extend Curbs at Street Corners/Tighter Curb Radii

Most pedestrian accidents occur at intersections. Curb extensions and tighter curb radii can make intersections safer for pedestrians by providing shorter pedestrian crossing distances, slowing traffic, and making pedestrians more visible at corners (Figure 7-8). Extensions often can be integrated with bus stops (e.g., bus bulbs).

In many settings, tighter curb radii may be appropriate (Figure 7-9). Both, tighter radii and curb extension at corners only work where:

- Curb parking is permitted on the streets involved; and
- Buses are not required to turn right.

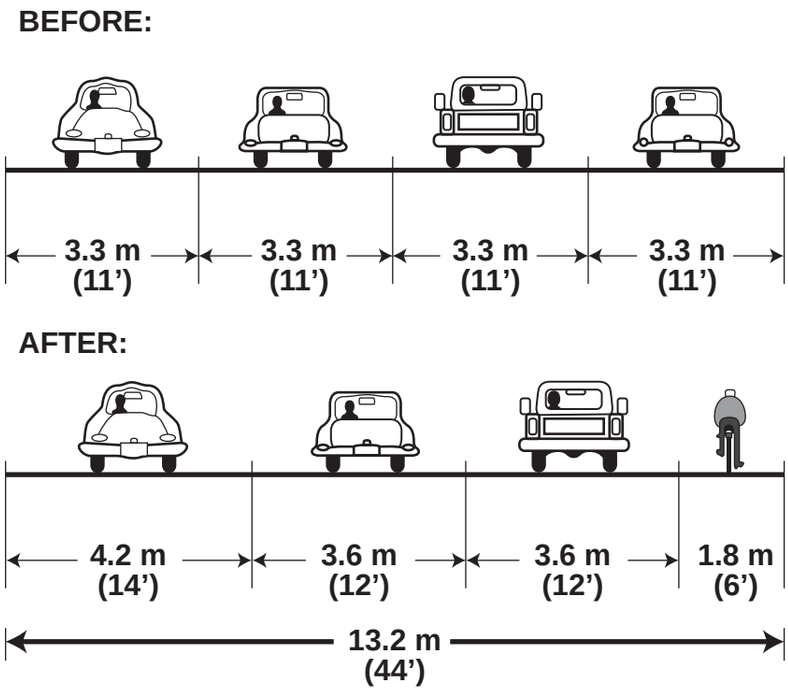


Figure 7-7. Example of Street Narrowing (*9*)

Figure 7-8. Curb Extension (*14*)

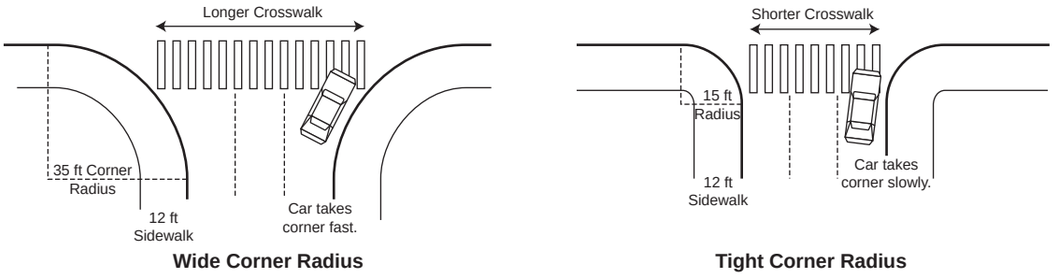


Figure 7-9. Corner Radii and Crossing Distance (*8*)

Tight curb radii and curb extensions may make it difficult for transit vehicles to turn. Therefore, they should be carefully analyzed where buses must turn.

Install Special Pavement

Pavement textures and colors can be an effective way to communicate crosswalk function and spatial relationships to pedestrians, particularly the visually impaired. When such treatments are used, crosswalks must be marked with solid, white, highly visible pavement markings with a friction component.

Care shall be exercised in using special paver stones or bricks:

- Street pavers can be difficult for wheelchairs and other people with disabilities to navigate because of the uneven surfaces. Bricks become worse with time because they settle at different depths.
- Cobblestone and granite blocks, while aesthetically pleasing, are not suitable for crosswalks.
- Colored pavements, where usable, should be clearly visible to motorists (Figure 7-10). Red has low contrast to black.
- Colored pavement in crosswalks should not use colors or patterns that degrade the contrast of white crosswalk lines, or that might be mistaken by road users as a traffic control application.

Transit stops should be located at or near convenient crossings. They should be placed near major traffic generators wherever possible (discussed further in Chapter 5).

Construct Grade Separations

Reducing distances that pedestrians must walk to reach transit stops can encourage transit use. Grade-separated over/under passes for pedestrians can reduce these distances, but they are expensive to construct, difficult to maintain, and may compromise the users' sense of security if not designed properly. Because pedestrians tend to cross where it is most convenient, grade-separated crossings usually are successful only where there are inadequate gaps in the traffic stream for crossing at grade. Grade-separated pedestrian crossings should be used only where it is not possible to provide an at-grade crossing. Considerations include heavy pedestrian traffic, large high-speed facilities, school routes, and where opportunities to cross at grade are limited (Figure 7-11). The following considerations should be assessed when designing a pedestrian grade separation:

- Grade changes should be minimized to the greatest extent possible.
- Elevated grade crossings are generally preferable to underpasses.

Figure 7-10. Textured Pavement Locating Bus Stops to Discourage Crossing Streets at Undesirable Locations (*13*)

Figure 7-11. Example Where Street Crossing Is an Extension of Railroad Crossing

- Railings 1.1 to 1.4 m (42 to 54 in.) high and designed so no object larger than a 150 mm (6 in.) sphere can pass through railing.
- Additional handrail where grades exceed five percent.
- Desirable width of 4.2 m (14 ft), minimum width of 3.0 m (10 ft) and vertical clearance of 3.0 m (10 ft) for tunnels.
- Minimum 4.4 m (14.6 ft) in vertical clearance above roadway.
- Lighting and complete vision from portal to portal (level profile).
- Protective screening to prevent thrown/dropped objects from bridge (as necessary); and
- Shared bicycle/pedestrian facilities reflecting a minimum width of 3.6 m (12 ft) and should match the width of the approaching facility.

7.1.5 Other Safety Treatments

Screen Surface Parking to Reduce Dead Space

On-street parking can provide a buffer between pedestrians and the street, but parking lots have become a major source of dead space in cities. Pedestrian counts have been shown in some areas to fall as the amount of open parking increases. An active pedestrian-oriented street frontage should be maintained by avoiding siting parking lots along sidewalks and street frontages. Where surface parking exists, screens should be used to minimize the visual impact. Figure 7-12 is an example of combined parking lot screening by using a screen wall and trees.

Following are general guidelines for screening parking lots.

- Local governments should require the screening of parking lots for new developments.
- A planting strip buffer of 3.0 to 3.6 m (10 to 12 ft) is desirable where space permits.
- Screens such as evergreen shrubs, walls, and fences between surface parking lots and sidewalks should be about 0.9 to 1.2 m (3 to 4 ft) high to maintain visibility into parking lots.
- Screens more than 1.2 m (4 ft) typically are used, and they should be made of semi-transparent materials and visually pleasing.

Use Natural Surveillance Near Transit Stops

A potential criminal is less likely to attempt a crime if he or she is at risk of being observed. Strategically locating transit stops in locations that have natural surveillance can help to reduce crime for pedestrians walking to or waiting at bus stops.

Natural surveillance occurs when the public can easily view what is happening around them during the course of everyday activities. Public spaces (parks, playground, plazas, gardens, squares, etc.) serve as attractions for pedestrians. Alternatively, locating bus stops near residential or commercial buildings that have windows facing the bus stop put potential criminal offenders under possible surveillance by

Figure 7-12. A Combination of a Screen Wall and Evergreen Landscaping Provide Parking Lot Screening (*4*)

observers living or working in the surrounding buildings. The following are examples of natural surveillance that a transit agency can directly use or influence:

- Locating concessions or coffee shops that look onto the transit facility;
- Designing bus shelters so they can be easily seen from a public space;
- Minimizing advertising or boards within a shelter that reduce visibility;
- Considering concessions or coffee carts in or near larger transit facilities;
- Encouraging mixed-use development; and
- Providing lighting at transit facilities.

Light Pedestrian Routes

Street lighting should be provided for sidewalks, walkways, and bike lanes to increase pedestrian and cyclist security, safety, and comfort. The street lighting systems usually found in urban areas sufficiently serve pedestrian sidewalks and walkways along streets. When designing a street lighting system, it is important to consider the security and comfort of pedestrians. Ideally, pedestrian-friendly lighting should be placed lower than standard streetlights and have less obtrusive and harsh light.

Following are some key guidelines:

- Uniformly space lighting to reduce contrasts between shadows and illuminated areas.
- Lighting of pedestrian facilities should complement that for motorists. It should be located at a lower level, and should be directed at sidewalks.

- Provide a lighting level generally between 0.5 and 2.0 ft candles along pedestrian travel ways, depending upon conditions.

Provide Weather Protection

Weather concerns should be addressed when pedestrian facilities are designed.

- Raised walkways through parking areas (with curb cuts to provide accessibility) help avoid the need for "puddle jumping" during wet weather and clearly define the pedestrian travel way.
- During winter, pedestrian facilities should be maintained at all times to keep them clear of snow and ice.
- To protect transit passengers from the elements, shelters are often installed. Shelters should not be placed on the wheelchair landing pad area. A shelter that is accessible to people in wheelchairs must have a minimum clear floor area 0.75 m (2.5 ft) wide and 1.2 m (4 ft) deep, entirely within the perimeter of the shelter.
- Shelters should be designed to provide as much protection as possible from sun, wind, and rain.
- When buildings are near the street, awnings, canopies, and arcades are desirable to protect pedestrians (including transit riders).

7.1.6 Enforce Streetscape

Buffer Traffic

Traffic "buffering" helps to separate pedestrians from vehicles. Buffering can enhance the pedestrian experience along a roadway as well as provide a safer environment. In general, the greater the speed along the roadway, the greater the buffering required (Figure 7-13). Design guidelines for buffering include the following:

- For design speed less than 30 km/hr (20 mph), sidewalks and vertical curbs can provide appropriate buffering.
- For design speed 30 to 55 km/hr (20 to 35 mph), sidewalks with planting strips or parking lane can create buffering.
- For design speed greater than 55 km/hr (35 mph), physical barriers should be provided. A row of trees in a strip between street and sidewalk is the best barrier. Street furniture, guardrails, or high curbs can be used to buffer pedestrians from traffic.
- Street lights, utility poles, parking meters, parked cars, or a bicycle lane also can buffer pedestrians.
- In rural areas, a wide shoulder can provide traffic buffering.
- Curbs that can be mounted by cars should be avoided, as the curbs do not provide a clear delineation between the roadway and the pedestrian zone.
- Narrowing lanes can create space for a buffer.

Figure 7-13. Example of Roadway with Buffering (*14*)

Provide Street Walls

Street walls such as storefronts or houses with buildings of similar height give pedestrians a visual enclosure. The street walls help define clear pathways for pedestrians along sidewalks. Finally, street walls of welcoming storefronts give pedestrians with a greater sense of security, and enhance the walking environment.

Provide Functional Street Furniture

Street furniture should be functional and should not obstruct sidewalks (Figure 7-14). The pedestrian walkway should be clear of physical obstacles. Streetlights, benches, garbage cans, newspaper stands, fire hydrants, overgrown plantings, utility poles, ground level signs, and sometimes even art and merchandise can obstruct pedestrian routes. But, when appropriately scaled and positioned, these items can help define the pedestrian environment and may provide a buffer from traffic when they are not within the pedestrian travel path.

Install Coherent, Small-Scale Signage

Signs can create a sense of place that enhances the overall pedestrian environment. Signs for pedestrians should be scaled down and be easy to read. Too many signs, especially when difficult to read, can create a chaotic atmosphere confusing pedestrians.

Figure 7-14. Example of Utility Box as Pedestrian Obstacle (*14*)

Roadway signs, designed for vehicles in motion, should clearly convey to both vehicles and pedestrians where the two sets of road users encounter each other. For instance, pedestrian crosswalks should be clearly marked with signs on both the side of the roadway. Transit signs should provide directional and rider information to transit users.

7.2 BICYCLE ACCESS

7.2.1 Bicycle Storage Location

Planners selecting locations for bicycle storage should consider the following guidelines (*5*).

- Bicycle racks should be placed at bus stops along routes where bus-mounted bicycle racks may be at capacity.
- Bicycle storage areas should be placed in defensible spaces that are physically and visually accessible. Placement along heavily traveled streets and walkways protect bicycles from theft and vandalism.

- Bicycle racks and lockers should not be placed in corners of parking garages or in other areas with low visibility.
- Bicycle lockers and racks should be located near streets with high vehicle and foot traffic to improve visibility.
- Bicycle racks should not be placed near sprinkler systems to avoid unnecessary water damage to bicycles.

7.2.2 Bicycle Storage Design

Design considerations for bicycle storage include the following (*4*):

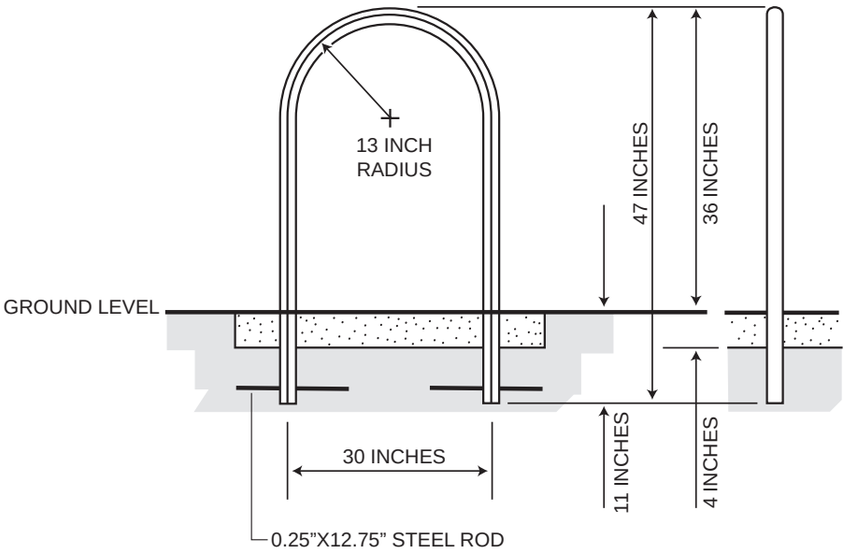
- Bicycle racks, where possible, should be kept underneath a covered area to protect the bicycles from exposure to the weather.
- Bicycle racks should support bikes by their frames at two points, an inverted "U" is a simple effective design (Figure 7-15).
- One person should be able to walk one bicycle through the aisle between the bicycle rack, 1.2 m (4 ft).
- 1.8 m (6 ft) of depth should be allowed for each row of parked bicycles.
- Racks should be located no less than 0.6 m (2 ft) from walls.
- Inverted "U" racks should be placed no less than 1.0 m (3 ft) apart width-wise.

7.2.3 Bicycle Lanes

Bicycle lanes generally are provided along the right edge of the traveled way. To reduce conflicts with pedestrians, cyclists are discouraged from using sidewalks. Cycling routes should be demarcated with pavement markings and signing to identify the preferred paths to building entrances, particularly where several routes exist (Promoting Sustainable Transportation Through Site Design: An ITE proposed Recommended Practice, CITE, 2004, p. 25). (*10*) Bicycle lane widths of 1.5-m (5 ft) or greater are recommended. Wider bicycle lanes and striped buffers are recommended on higher speed and higher volume roadways. For additional guidance see *AASHTO Guide for the Development of Bicycle Facilities.*

When designing bicycle lanes, conflicts with other modes of transportation (such as bus lanes or right turn lanes) should be minimized. If a conflict is inevitable, the shared area should be marked for visual attention (i.e., dashed line pavement markings where potential conflicts exist, as shown in the MUTCD), as in approaches to intersections or through a bus stop.

Some jurisdictions combine bus and bicycle lanes into a single shared lane giving, preferential treatment to both modes of travel. Often the lanes are also used by taxis and right-turning vehicles. In these instances, lane width is important and can vary from 4.2 m (14 ft) when bicycle and bus traffic is low to 4.8 m (16 ft) where the numbers are higher. Obviously, when bus flows are heavy, it is better to locate bus lanes parallel to the bicycle lane and not to share that lane.



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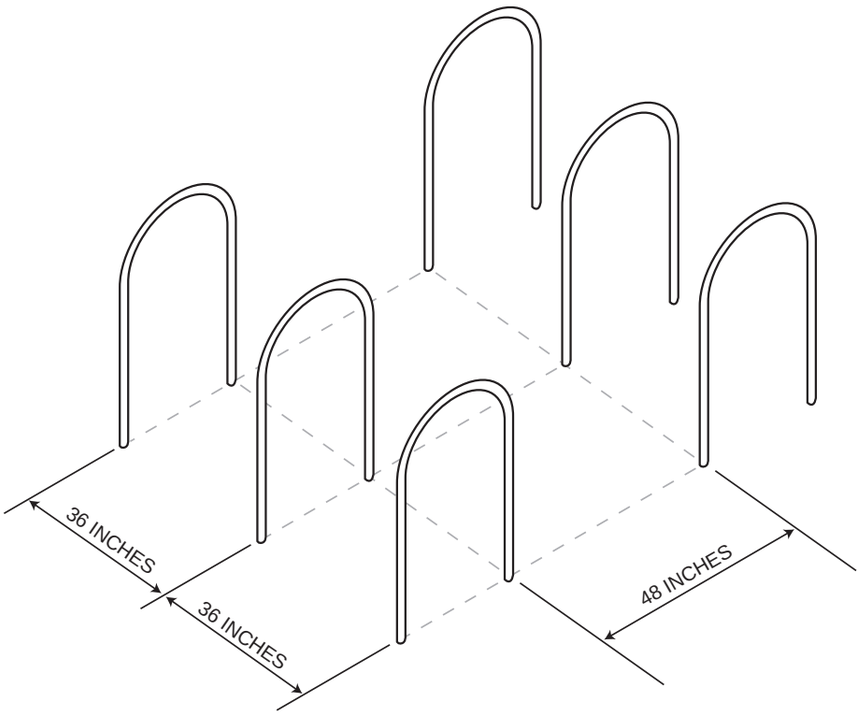

Not to Scale

Source: Access Transit Design Handbook for Florida Bus Passenger Facilities, p. 3.

Figure 7-15. Bike Rack Dimensions and Spacing (*2*)

7.3 PASSENGER AMENITY/AESTHETIC CONSIDERATIONS

When considering transit over other means of travel, potential passengers weigh the comfort and convenience of the competing modes, especially the private vehicle. In considering transit, passengers ask themselves questions such as:

- How long is the walk? Can I walk safely along and across the streets leading to and from transit stops? Is there a functional and continuous accessible path to the stop? What does the walk "feel" like?
- How long is the wait? Is a shelter available at the stop while I wait?
- How comfortable is the trip? Will I have to stand? Are the vehicles and transit facilities clean?
- Are there security concerns while walking, waiting, or riding?

Passenger amenities provided at transit stops or stations enhance comfort, convenience, and security for the passengers (Figure 7-16). People waiting at stations for a bus or streetcar need safe, comfortable, attractive, and plentiful facilities. Sufficient shelter from inclement weather, seating, customer

Figure 7-16. Attractive Station Area (*9*)

Table 7-5. Passenger Amenities Advantages and Disadvantages

Amenity	Advantages	Disadvantages
Shelters	• Provide comfort for waiting passengers. • Provide protection from climate (sun, glare, wind, rain, snow). • Help identify the stop/station.	• Require maintenance, trash collection. • May be used by graffiti artists.
Benches	• Provide comfort for waiting passengers. • Help identify the stop/station. • Low-cost when compared with installing a shelter.	• Require maintenance. • May be used by graffiti artists.
Vending Machines	• Provide reading material for waiting passengers.	• Increase trash accumulation. • May have poor visual appearance. • Reduce circulation space. • Can be vandalized.
Lighting	• Increase visibility. • Increase perceptions of comfort and security. • Discourage "after hours" use of bus stop facilities by indigents.	• Require maintenance. • Can be costly.
Garbage Receptacles	• Provide place to discard garbage. • Keep bus stop and surrounding area clean	• May be costly to maintain. • May be used by customers of nearby land uses. • May have a bad odor. • May be removed for security reasons.
Bicycle Parking	• Increase use and convenience for cyclists. • Prevent damage caused by bike being locked to benches and signs.	• Require maintenance. • Can be vandalized.
Telephones	• Convenient for transit patrons. • Provide access to transit information and emergency services.	• May encourage loitering at bus stop. • May encourage illegal activities at bus stop.

information (maps and schedules), appropriate lighting, and ample platform space for boarding, alighting, and waiting are the minimum requirements. Additional amenities, such as winter heating, electronic real-time passenger and next bus arrival information, and services such as coffee shops, newsstands, and bank machines all make the stations more comfortable and attractive for users.

Many transit providers have fare-free zones, where people can ride within a defined boundary without paying. Weather and other factors may influence ridership within the limits of the fare-free zone. People who do not normally ride transit may use it in the fare-free zone. Fare-free users should be considered when determining bike parking and other amenities.

Table 7-5 lists advantages and disadvantages of several amenities. Figure 7-16 shows an example of well-designed station.

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