Bus Rapid Transit on City Streets

How Does It Work

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ABSTRACT

Bus rapid transit systems have grown in popularity. Most existing and proposed BRT lines operate on city streets for all or a portion of their routes. They may run in mixed traffic; normal or contra-flow curb bus lanes, and/or arterial median busways. This paper describes the design, operations, and effectiveness of each; and identifies the key issues and tradeoffs. Drawing on ongoing research (TCRP Project A-23), it gives illustrative examples of usage, costs and benefits. It shows that with proper design, BRT can improve bus speeds, reliability and identity, while minimizing adverse impacts to street traffic, pedestrian and property access.

INTRODUCTION

Bus rapid transit (BRT) is growing in popularity throughout the world. In the United States its development has been spurred by the Federal Transit Administration's BRT initiatives. BRT is perceived as an environmentally responsive and cost effective means of urban mobility. It provides more operating flexibility, adapts better to stage development and generally costs less than rail transit.

The general perception of bus rapid transit is one of buses operating on their own running ways generally unimpeded by the general traffic flow – such as in Brisbane, Miami, Ottawa and Pittsburgh. But there are a growing number of systems that operate totally or mainly on city streets – such as those found in Cleveland, Los Angeles and Vancouver in North America, and in Bogota, Curitiba, and Quito in South America. However, even busway bus rapid transit routes usually operate on city streets in downtown areas and/or in local collection and distribution.

This paper describes the design, operations, and effectiveness of BRT operations on city streets. It identifies the key issues and tradeoffs. Drawing on on-going research (TCRP Project A-23)[(1)] it gives illustrative examples of each type of running way, including usage, costs and benefits. It shows that with proper design BRT can improve bus speed, reliability, and identity while minimizing adverse impacts to street traffic, pedestrian movement, and property access.

BRT – AN INTEGRATED SYSTEM

There are many definitions of bus rapid transit. The Federal Transit Administration defines BRT as a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses. TCRP A-23 defines BRT as a flexible rubber tired rapid transit mode that combines stations, vehicles, services, running ways, and intelligent transportation systems (ITS) elements into an integrated system with a strong identity. BRT applications are designed to be appropriate to the market they serve and their physical surroundings, and they can be incrementally implemented in a variety of environments (from rights of way totally dedicated to transit – surface, elevated, underground – to mixed with traffic on streets and highways.[(1)]

In brief, BRT is an integrated system of facilities, services, and amenities that is designed to improve the speed, reliability and identity of bus transit. It is essentially rubber-tired LRT, but with greater operating flexibility and potentially lower costs since a relatively small investment in special guideways often can provide regional rapid transit.

The major components include:

- Running Ways that are clearly identifiable, free from traffic interferences wherever possible, and permit rapid and reliable service.
- Vehicles that are distinctive in design, easy to board and alight and provide multiple doors.
- Stations that are attractive, provide passenger protection and amenities, permit off-vehicle fare payments, and are generally spaced far apart.
- Application of ITS to monitor bus performance, provide traffic signal priorities and passenger information, and permit precise berthing at stations.
- Service patterns that are clear, easy to use, and include high-frequency trunk-line operations and feeder routes.
- Land-use and parking policies that reinforce, rather than undercut, transit ridership.

GENERAL GUIDELINES

The planning, design, and operational guidelines for BRT operation on city streets have been well articulated. They include the following:

1. *Running ways should serve and penetrate major travel markets. They generally should be radial, connecting the city center with outlying residential and commercial areas.* Crosstown running ways may be appropriate in large cities where they connect major passenger generators, serve large residential catchments, and have frequent interchange with major bus lines.

2. *BRT should use streets and roadways that are relatively free-flowing wherever possible.* Speeds and reliability should be enhanced by transit-sensitive traffic engineering of bus-only lanes, and in some cases major street improvements. Routes should be direct, and the number of bus turns should be minimized.

3. *Special running ways (busways, bus lanes, and queue bypasses) should be provided where there is (1) extensive street congestion; (2) a sufficient number of buses; (3) suitable street geometry; (4) community willingness to support public transport, reallocate road space as needed, provide necessary funding, and enforce regulations*.

4. *Running ways should maximize the person-flow along a roadway with a net savings in the travel time per person.* Where road space is allocated to BRT, the person-minutes saved should exceed the person-minutes lost by people in cars. There should be a net economic gain to the community.

5. *Buses should be able to enter and leave running ways safely and conveniently.* Conflicts with other traffic should be avoided and carefully controlled where necessary. This is especially important for contra-flow bus lanes and median busways along arterial streets. There should be suitable provisions for passing stopped or disabled buses. New problems should not be created, nor should existing problems merely be transferred from one location to another.

6. *Running ways should provide a strong sense of identity for BRT.* This especially important where buses operate in bus lanes or in arterial median busways. Giving the lanes a special color (e.g. pink) is desirable.

7. *Design and operation of bus lanes (and arterial median busways) must accommodate the service requirements of adjacent land uses.* Deliveries should be prohibited from curb 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 contra-flow lanes are provided.

8. *BRT lane widths should accommodate the anticipated BRT fleet*. Concurrent flow bus lanes generally should be at least 11-feet wide for 8.5-foot wide buses; 12 to 13-foot wide bus lanes are desirable. Contra-flow bus lanes should be at least several feet wider in areas of heavy pedestrian flow to let buses pass around errant pedestrians in the lanes. Bus streets and arterial median busways should be at least 22-feet wide.

9. *BRT bus lanes, streets and busways should operate throughout the day wherever possible*. This will give passengers a clear sense of BRT presence.

10. *Bus lanes, busways, and bus streets must be perceived as reasonable by users, public agencies and the general public*. There should be a "strong presence" of buses in the lanes, (for example one bus per traffic signal cycle).

11. *There should be a reasonable allocation of street space to BRT, and to other street users*. For example:

	% of street space	% of peak-hour, peak direction flow
Bogota		
TransMilenio 4-lane Median Arterial Busway	>50	>85
New York City		
Madison Avenue PM Peak Hour Bus Lanes	40	>75
Cleveland		
Euclid Avenue Median Arterial Busway	50	50

12. *Police cars, fire equipment, ambulances and other emergency vehicles should be pemitted to use running ways.* Other traffic generally should be prohibited.

13. *Bus routes should be restructured as necessary to make effective use of bus lanes and bus streets*. Where BRT vehicles exceed 40 buses per hour, they should have exclusive use of the running way. When service is less frequent, local buses can operate on the same facility, since they would not create bus-bus congestion or create passenger inconvenience. Peak hourly (one-way bus volumes ranging from 60 to about 75 buses will help "enforce" bus lanes without excessive bunching of buses.

14. *Intelligent Transportation Systems (ITS) applications are desirable to monitor bus performance, systematically allow traffic signal priorities, provide passenger information at bus stations, expedite fare collection, and facilitate precise docking at BRT stations.*

TRAFFIC ENGINEERING

Effective traffic-transit integration is essential. Traffic engineers and transit planners should work together in developing bus lane and busway designs, locating bus stops, and applying traffic controls. The goals are to (a) minimize delays along roadways for both buses and cars; (b) ensure safe and reliable pedestrian access to BRT stops; and (c) maintain essential access to curbside activities.

The specific traffic engineering techniques will vary with the type and location of BRT running ways. They generally include (a) curb adjustments, changes in roadway geometry and pavement markings; (b) curb parking and loading controls; (c) left and right turn controls; (d) one-way street routings; and (e) traffic signal controls including BRT priorities.

Parking Restrictions

Parking generally should be restricted along BRT routes in congested areas and along heavily travel arteries at least during rush hours. However, parking can be retained along street with "interior" or median bus lanes, or along lightly traveled streets where "bus bulbs" can be provided for passenger convenience. As a general guide, curb parking should be prohibited when traffic volumes exceed 500 to 600 vehicles per lane per hour, the streets operate at auto speeds below 20-25 mph and the lanes are needed for bus or BRT use.

BRT Stops

BRT bus stops and stations generally should be located on the far-side of intersections. The far-side locations separate lanes removed from right-turn conflicts, and they are essential wherever traffic signal priorities are provided. Where BRT and local buses operate on the same street (as along Wilshire Boulevard in Los Angeles) local buses could stop on the near side of intersections.

Bus Bulbs

Bus bulbs may benefit BRT operation by creating additional space for amenities at bus stops; reducing street crossing distances for pedestrians; eliminating lateral movements of buses into and out of stops; eliminating delays associated with buses reentering a traffic stream, or segregating waiting bus passengers from pedestrian flow along a sidewalk. However, they may result in queuing traffic behind stopped buses causing auto drivers to change lanes to avoid a stopped bus, precluding adding capacity for moving traffic, and costing more than conventional bus stops. Supporting conditions include (1) frequent bus service; (2) high levels of boarding and alighting; (3) curb parking; (4) low auto operating speeds; (4) two travel lanes each way; (5) difficult bus re-entering problems. Bus bulbs may be located near side, far-side, or mid-block. When far-side us stops are used, right turn lanes can be provided on intersection approaches by removing several parking spaces.

Turn Controls

Left and right turn restrictions re desirable wherever the turns delay BRT. Right turn restrictions may be appropriate at locations where BRT operates in mixed traffic, curb bus lanes, or "interior" bus lanes, and where both right turns and pedestrian volumes are heavy. Left turns generally should be prohibited where the turns share lanes with through traffic; they also may be prohibited where turns can be made from nearby roadways that parallel the BRT line. Where BRT operates in median arterial busways, left turns should be prohibited from the adjacent roadways unless left turn lanes and protected traffic signal phases are provided.

One-way Streets

One-way streets can facilitate BRT, car, and truck flows, and can improve safety. They are essential in downtown street grids with narrow and closely spaced blocks. They may be disadvantageous from a BRT perspective since they divide service onto two streets, reduce BRT presence, and limit the curb faces available for receiving and discharging passengers. Sometimes these concerns can be overcome by running buses two-way on one of the one-way streets.

Traffic Signals

Signal displays and locations should be consistent with those set forth in the Manual of Uniform Traffic Control Devices, Millennium Edition[2]. The "Transit Signal" displays for light rail transit vehicles should be used for BRT where buses operate along median arterial busways and in queue bypass lanes.

Bus delays at traffic signals account for about 10 to 20% of overall bus travel times. Therefore, setting signals to minimize person-delay is essential to improve BRT running times and reliability. This can be achieved by "passive" signal controls that minimize the number of phases, keep cycle lengths as short as possible, and maximize the "green" times along BRT routes.

Special signal phases, either pre-timed or pre-empted, should be provided where BRT conflicts with other movements. Active signal priorities that advance or extend the green time within established cycles can reduce BRT travel times and improve their variability. They may be unconditional (occur any time the buses arrive in the designated time window) or conditional (only when the buses arrive late). Los Angeles Metro Rapid Buses operating on Wilshire Boulevard reduced running times about 10% as a result of signal priorities, and similar gains have been reported in other cities. The person-minutes saved by bus and car passengers long the BRT route should exceed the person-minutes lost by side-street auto passengers; adequate clearance time for pedestrians crossing the artery should be provided; and queues on side streets should be manageable.

Signal priorities also can be used in conjunction with queue bypasses and "gating" to reduce delays and facilitate bus re-entry into the traffic stream. Queue bypasses give buses a few seconds of early green. Gating creates a midblock signalized intersection, in which the buses move on the same phase as the downstream cross street.

Enforcement

Effective enforcement of curb parking restrictions along BRT routes is essential, since public perceptions of violations can affect the respect and support for BRT. Enforcement should be done by jurisdictions that have primary responsibility for the BRT running ways on a sustained basis, and penalties for violations (e.g. fines, towing) should be stringent. New York City, for example, charges a $100 fine plus towing charges for illegally parking in the Madison Avenue Dual Bus Lanes.

RUNNING WAY TYPES AND EXAMPLES

Examples of the various types of city-street BRT running ways in North America, Europe, and South America are given in Table 1. A further description of the features, strengths, and weaknesses of each type follows.

"Traditional" BRT Running Ways

The traditional BRT running ways include mixed traffic operations; single and dual concurrent flow curb bus lanes; single and dual contra-flow bus lanes; concurrent flow interior bus lanes; and bus-only streets.

Mixed Traffic Operations

BRT operates in mixed traffic flow where physical, traffic, land-use and environmental conditions preclude busways or bus lanes, where streets are "free flowing; on "branch" BRT lines; and in residential collection. Advantages include low costs and fast implementation. However, mixed traffic operation can limit BRT speeds, reliability, and identity. It should be used sparingly on trunk line BRT routes. Examples include Los Angeles' Metro Rapid Lines along Wilshire-Whittier and Ventura Boulevards, Honolulu's City Express! and Vancouver's Broadway-Lougheed "B" Line.

Buses will benefit from street and traffic improvements that reduce overall delay. The range of transit-related traffic improvements includes: grade separations to bypass delay points; street extensions to improve traffic distribution or to provide bus routing continuity; intersection channelization; traffic signal improvements such as system coordination, modernization, and bus priorities; turn controls that exempt buses; bus stop lengthening or relocation; longer curb radii and corner rounding; effective enforcement and extension of curb parking regulations especially during peak periods; and improved spacing and design of bus stops.

Los Angeles operates Metro-Rapid bus service along 26 miles of Wilshire Boulevard and 14 miles of Ventura Boulevard. The integrated system of BRT features include (1) simple route layouts since there are no turnbacks or branches; (2) frequent service with (headways as low as 2 to 3 minutes); (3) wide station spacing (usually more than a mile between stops); (4) distinctive, easily identifiable red-colored, low-flow low-pollution buses that allow level boarding and alighting; (5) simple, yet attractive stations with automated passenger announcements, and bus signal priorities – buses can extend or advance the queue time at most intersections.

The BRT routes utilize far-side stations, while the local bus lines use near-side stops. Both routes serve as extensions of the Red Line subway – to the San Fernando Valley via Ventura Boulevard from the Universal City Metro-Rail station and to Western Los Angeles via Wilshire Boulevard from the Vermont Station.

Daily bus ridership averages 40,000 on Wilshire Boulevard and 9,000 on Ventura Boulevard. Operating speeds have increased about 29% in the Wilshire-Whittier corridor and ridership has increased by 33%. In the Ventura Boulevard corridor, operating speeds increased by 23% and ridership grew by roughly 26%. Two-thirds of the travel time savings were from the wider stop spacing, and one-third from traffic signal priorities. About one-third of the increased ridership comes from riders new to transit.

Concurrent Flow Curb Bus Lanes

Concurrent flow curb bus lanes are the most common type of bus priority treatment, but have not been extensively used for BRT. Traditionally, they have been used to facilitate bus movements in central business districts by segregating buses from other traffic. They may be single lanes as those for Boston's Silver Line BRT or dual lanes as found along Madison Avenue, New York City.

Curb bus lanes are the easiest priority treatment to implement and have the lowest installation costs since they normally involve only pavement markings and street signs. They occupy less street space than most other types of bus lanes. The lanes are usually least effective in terms of image afforded and travel time saved. They are difficult to enforce and may impact curb access. Right turns, when permitted, conflict with bus flow.

On one and two-way streets, an 11 to 13-foot bus lane should be provided along the curb. However, where street width permits and there are high demands for curb access, a 20-foot wide curb bus lane can enable buses to pass loading and unloading cars and trucks. (This arrangement is used in downtown San Francisco).

Where street width and circulation patterns permit and peak bus volumes exceed 90 to 100 buses per hour, “dual” bus lanes should be considered. This arrangement enables buses to pass each other safely, make skip-stops feasible, and reduces the magnitude and variance of bus travel times. However, dual lanes preclude right turns by general traffic.

Curb lanes can be separated by solid white lane lines, by paving materials with a different color or texture, or sometimes by curbs. The lane lines should be broken where right turns are permitted. Every effort should be made to eliminate turning movements that would impede BRT service.

Concurrent Flow – Interior Bus Lanes

These BRT lanes can be provided adjacent to the parking lanes on both one-way and two-way streets. Examples of such lanes are found in downtown Ottawa (Figure 1) and along Washington Street in Boston where they serve the Silver Line BRT.

The lanes remove buses from most curbside conflicts with illegally parked vehicles, and they do not affect left turn access. Right turns can be permitted from the bus lane, or provided in the curb lane by prohibiting curb parking on intersection approaches. Bus bulbs can be provided on the far side of intersections. Parking can be retained at all times during off-peak periods. Where parking is retained, and parking and unparking maneuvers may conflict with BRT vehicles.

The lanes normally require wide streets, typically 60 and 70 feet with and without left turn lanes respectively. They should be at least 11-feet wide and be clearly delineated by pavement markings, texture and/or color.

Contra-flow Bus Lanes

Single and dual contra-flow lanes enable buses to operate opposite to the normal traffic flow on one-way streets. However, they may be used for a single block on two-way streets to enable buses to reverse direction. They normally operate at all times. They are used for distribution of busway vehicles in downtown Los Angeles (Spring Street) and downtown Pittsburgh.

Contra-flow lanes can retain existing bus routes when new one-way street patterns are introduced with savings in bus miles, hours, and operating costs. They allow new bus service on existing one-way streets, utilize available street capacity in the off-peak direction 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 not affected by peak hour queues at signalized intersections. The lanes provide a high degree of bus service reliability, and identity, and they are “self enforcing” since the presence of violators is easily detected.

Contra-flow lanes have a varied accident history. Total accidents drop when the lanes operate on a street that previously was two way. When the lanes operate on a street that previously was one-way, an increase may occur especially initially. The predominant accident causative factor is the inability of crossing pedestrians to recognize a street's "wrong way" operation, since individuals look only in the general traffic direction when crossing.

From a BRT perspective, the lanes have several disadvantages: (1) they disperse buses onto two streets, thereby detracting from BRT identity; (2) passing stopped or disabled buses is difficult unless dual bus lanes are provided; (3) buses run "against" the established traffic signal progression, especially along radial arterial street couplets. Contra-flow bus lanes should be at least 12 feet wide; however, a 13 to 15-foot wide lane is desirable to let buses pass around errant pedestrians who step off the curb. Left turns in the opposing direction of travel should be prohibited unless protected storage lanes and special traffic signal phases are provided. Loading of goods should be prohibited from the lanes at all times, unless special space is provided for midday loading.

Contra-flow lanes may be provided in the next lane from the curb, allowing delivery and service vehicles to use the curb lane. This improves their ability to provide access to adjacent properties and improves pedestrian safety, but it requires an extra lane of road space. Such a treatment was installed on Sansome Street in downtown San Francisco in 1997.

Pedestrian safety can be improved by (1) strict enforcement of "jay-waling" ordinances; (2) pedestrian signing and marking stating "LOOK BOTH WAYS" at designated cross-walks; (3) special visual or audible warning devices installed on contra-flow lane buses; and (4) a special yellow stripe of one to two feet (0.3 to 0.6m) width with a warning message painted on the sidewalk adjacent to the curb. Buses should operate with their headlights on at all times, so they can be seen easier by the pedestrians, such as along Spring Street in Los Angeles.

Median Bus Lanes

These lanes are located in the center of a roadway for exclusive bus use. They may operate one-way or two-way depending upon the street travel directions. Perhaps the first median bus lane in the United States operated along Washington Street in downtown Chicago from the early 1950's to the mid-1970's. A 48-foot wide one-way street provided two curb access lanes, two moving traffic lanes, plus the median bus lane and three-foot wide passenger loading areas. However, such space conserving designs would not work in 2003 because of wider buses, and ADA requirements.

Continuous access to and from the lanes can be provided enabling buses to readily pass around disabled vehicles, but making enforcement difficult. Therefore, they should be used sparingly in BRT operations.

Bus Streets

Bus streets can provide early action cost-effective downtown distribution for both BRT and local buses by fully separating bus and car traffic. They may be warranted where high bus volumes traverse narrow streets or as part of downtown revitalization 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; downtown us malls; and bus circulation through auto-free bus zones. Existing bus streets such as the 5th and 6th Street Bus Malls in Portland, Nicollet Mall in Minneapolis, and Fulton Street Brooklyn serve local buses.

Bus streets clearly identify transit routes, are easy to enforce; they increase walking space for pedestrians and waiting space at stops. But as their use by buses increases, they may become less attractive for pedestrians. Thus, they are a compromise between giving buses unhindered passage, and providing freedom of pedestrian movement.
Bus streets should incorporate curb loading zones for off-peak service vehicles where the necessary service cannot be provided from intersecting streets or off-street. Where other options are not practical, pickups and deliveries can be permitted from the bus streets when the bus traffic is low (i.e., night hours). Access to parking garages is a constraining factor that may require car use for short discontinuous sections of street. Such an arrangement is incorporated in Portland Oregon's dual-lanes one-way 5th and 6th Avenue bus streets; cars must turn off at the first cross street after leaving the parking garage.

Bus streets should provide passing opportunities around stopped buses where (1) bus flows are heavy; (2) the distances involved are more than ½ mile, and (3) both BRT and other buses used the street. Stopping positions for BRT should be separated from those for local buses.

Illustrative designs are shown in Figure 2. A 22 to 24-foot two-way road is adequate where there are less than 50 to 60 peak-hour buses one-way. When there are more than 50 buses per hour, it is desirable to provide passing opportunities at stops. The stops usually should accommodate at least three buses but they may extend an entire block where blocks are closely spaced. In cases of very heavy bus volumes, (e.g. over 90 buses per hour), dual lanes may be desirable in each direction. Specific designs can include bus pull-outs, central medians at key points, widened sidewalks, connections to skywalk systems and passenger amenities.

Median Arterial Busways – A "New" Old Concept

Median arterial busways are physically separated roadways that are located in the center of wide two-way streets. They place the bus running ways where street cars once ran, and LRT vehicles now operate. They are, in a sense, part of a "transit priority cycle" that has progressed from street cars on their own reservation, to street cars in mixed traffic, to buses in mixed traffic, to buses in curb bus lanes, and to buses and LRV's in center median reservations.

Median arterial busways operate on the Canal Street, New Orleans "neutral ground", and in Richmond, British Columbia along the B-98 line. They are under development in Cleveland, Eugene, and Minneapolis. Their development has been given impetus by their widespread use in South America. Curitiba and Sao Paulo, Brazil; Bogota's four-lane TransMilenio busway and Quito's Trolebus are the more innovative applications.

The busways completely separate BRT from other arterial traffic, thereby eliminating the passenger loading, curb access, and right turn problems associated with curb lanes. They can be readily enforced and provide a strong sense of identity (preferably specially colored pavement) and attractive stations. They can be grade separated at major intersections where space permits.

However, they usually require wide roadways since they superimpose three to four lane envelopes for the bus lanes and stations on the available street space. When passing lanes for buses are provided – as in South American cities – additional street space is required. They may require long cycle lengths to enable safe pedestrian crossings and provide protected phases for left turns. Stations may be less accessible than for curbside stops.

Design Envelope

Curb-to-curb width at stations should be based upon the following dimensions:

Curb Access Lanes	8 feet each
Travel Lanes	10 to 12 feet each
Barriers	2 to 4 feet
Left Turn lanes	10 feet
Busway	22 to 24 feet
Station Platform	8 to 10 feet

Curb-to-curb widths generally range from 75 to 90 feet. In most situations a 100-foot width is desirable to provide wider lanes and/or space for landscaping.

- A single curb traffic lane without any provision for curbside access should only be provided for one or two blocks where road space is seriously constrained

- Left turns from general traffic lanes should be discouraged; where provided, they should be signal controlled

- The "mid block" reserve space between the BRT running way could be devoted to bus passing lanes at selected locations or to parking

Design Features

Designs should be keyed to the available curb widths, and the needs for left turns and curb access. Figure 3 gives a conceptual design for a wide arterial boulevard that provides these functions. It also identifies desired treatments for turn lanes and bus stops, signal controls, pedestrian access, "escape" lanes and cross street closures. (1) Buses may join the general traffic flow at busway terminal points; however, special signal controls will be needed where buses turn right or left. (2) Intermediate entry and exit points can be provided via slip ramps where space permits. (3) Traffic signals should control movements at crossing roads. The buses should move on the green phase for through traffic that is <u>followed</u> by the left turn phase. (This sequence is essential to minimize same-direction bus-car crashes). (4) Pedestrian access to the stations should be provided at signalized intersections. (5) The space used by traffic signal-controlled near-side left turn storage lanes should be shared with the far-side bus station platforms. (6) Bus stops located in the islands must have passenger protection, and fencing is desirable to channel pedestrian entry and exit to intersection cross walks.

Most rights-of-way will require more space-frugal designs (See Figure 4). Where left turns are prohibited, the basic busway plus station envelope can be reduced from four to three lanes. This, however, calls for offsetting the busway about 6 to 8 feet at stations.

A “staggered” station platform arrangement used in several Brazilian cities provides a center lane for “express buses” whose direction alternates. This results in a three-lane busway-plus-station envelope. However, general traffic left turns are prohibited at stations. (See Figure 5).

PERFORMANCE AND EFFECTIVENESS

Performance and effectiveness can be measured by passengers carried, ridership growth, operating speeds, travel time savings and land development impacts.

Ridership

Weekday riders for selected U.S., Canadian and South American BRT systems are given in Table 2. Within North America, ridership ranges from 9,000 on the Ventura Boulevard Metro Rapid up to 40,000 on the Wilshire Boulevard Metro Rapid. As would be expected, reported ridership is substantially higher in South American cities, ranging from 150,000 daily riders in Quito up to 800,000 on Bogota’s TransMilenio Busway.

Table 3 gives AM peak-hour peak direction riders at maximum load points. The Los Angeles and Vancouver systems have less than 2,000 riders. In contrast, the South American systems have ridership ranging from 8,000 in Quito to 27,000 in Bogota.

Speeds and Travel Times

Reported operating speeds are shown in Table 4. Speeds generally are under 15 mph. However, the Ventura Boulevatrd Metro Rapid, and express service in Bogota and Curitiba achieve speeds of 19 mph.

Travel time saving resulting from BRT service are shown in Table 5. Reductions range from about 20% in Cleveland upward to over 30% in Bogota and Honolulu. The savings generally range from about 1 to 2-minutes per mile.

Land Development Benefits

Curitiba has restructured the city along its BRT routes as a result of coordinated land use and transportation policy. Land development benefits along other BRT lines only on city streets were not observed.

CONCLUSIONS

BRT on city streets works! It can attract riders, reduce travel times, and improve service reliability. It may be the only practical running way in many cities, and it can provide the first stage of future busway systems in others.

However, for BRT to really be rapid, and provide speeds that are competitive with driving, a substantial part (e.g. half) of the BRT system should operate on separate traffic-free rights-of-way. In these cases BRT on city streets can provide an essential part of the overall system.

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2. Manual of Uniform Traffic Control Devices for Streets and Highways, Millennium Edition. American Association of State Highway and Transportation Officials, Washington, D.C., 2001.

ILLUSTRATIONS

Source: Levinson, H.S., Zimmerman S., et al, TCRP 90, Bus Rapid Transit, Volume 1, Case Studies in Bus Rapid Transit. Transportation Research Board, National Research Council, Washington, D.C., 2003.

TABLE 1

EXAMPLES OF BRT RUNNING WAYS ON CITY STREETS

Mixed Traffic	*	Wilshire-Whittier and Ventura Boulevard Metro Rapid, Los Angeles
	*	Broadway 'B' Line, Vancouver
	*	City Express, Honolulu
Concurrent Flow Curb Bus Lanes	*	Boston, Silver Line
	*	Madison Avenue, New York City (Dual lanes)
Concurrent Flow Interior Bus Lanes	*	Silver Line, Boston
	*	Downtown Ottawa
Contra Flow Curb Bus Lanes	*	Spring Street, Los Angeles
	*	Downtown Pittsburgh
Median Arterial Busways	*	'B' Line, Richmond, Vancouver
	*	Euclid Avenue, Cleveland
	*	Eugene-Springfield (Oregon)
	*	Avenida Christiana, Belo Horizonte, Brazil
	*	TransMilenio (Bogota) Columbia
	*	Curitiba
	*	Assis Brazil – Farrapos and Porto Alegre
	*	Trolebus (Quito) Ecuador
	*	9 de Julho and Jabaquaro, Sao Paulo, Brazil
Bus Streets	*	Fifth and Sixth Streets, [a,b] Portland, Oregon
	*	Nicollet Mall, Minneapolis, Minnesota

Source: Levinson, H.S., Zimmerman S., et al, TCRP 90, Bus Rapid Transit, Volume 1, Case Studies in Bus Rapid Transit. Transportation Research Board, National Research Council, Washington, D.C., 2003.

[a] dual lanes
[b] for local buses

TABLE 2

REPORTED DAILY RIDERSHIP
BRT ON CITY STREETS

City	Facility	Weekday Riders
Cleveland	Euclid Ave Median Arterial Busway	30,000 (1)
Honolulu	Route B City Express	11,000
Los Angeles	Wilshire-Whittier, Metro Rapid	40,000(2)
	Ventura Boulevard, Metro Rapid	9,000(2)
Vancouver	Broadway "B" Line	26,000
	Richmond "B" Line	14,000
Bogota (Columbia)	Trans-Milenio Dual Median Arterial Busway	800,000
Curitiba (Brazil)	Median Arterial Busway System	345,000
Quito (Ecuador)	Trolebus Median Arterial Busway	150-170,000
Sao Paulo (Brazil)	Jabaquaro Median Arterial Busway	230,000
Sao Paulo (Brazil)	9 de Julho Median Arterial Busway	196,000

(1) Forecast
(2) BRT Riders Only

Source: Levinson, H., Zimmerman, S., et al, TCRP Report 90, Bus Rapid Transit, Volume 1, Case Studies in Bus Rapid Transit, Transportation Research Board, National Research Council, Washington, D.C. 2003.

TABLE 3

REPORTED PASSENGER VOLUMES AND BUS FLOWS ON CITY STREETS PEAK DIRECTION – A.M. PEAK HOUR

City	Facility	Buses	Riders
Los Angeles	Wilshire-Whittier Metro Rapid	30	1,500
	Ventura Metro Rapid	15	750
Vancouver	Broadway "B" Line	15	1,000
	Richmond "B" Line	15	1,000
Belo Horizonte Brazil	Ave Christiano Machado Median Arterial Busway	NA	16,000
Bogota Columbia	TransMilenio Median Arterial Busway	NA	27,000
Curitiba Brazil	Median Arterial Busway	40	11,000
Porto Alegre Brazil	Assis Brasil Median Arterial Busway	326	26,100
	Farrapos Median Arterial Busway	364	17,500
Quito Ecuador	Trolebus Median Arterial Busway	40	8,000
Sao Paulo Brazil	9 de Julho Median Arterial Busway	220	18-20,000
Sao Paulo Brazil	Jabaquaro Median Arterial Busway	NA	21,600

Note: (Ridership at Maximum Load Point)

Source: Levinson, H., Zimmerman, S., et al, TCRP Report 90, Bus Rapid Transit, Volume 1, Cast Studies in Bus Rapid transit, Transportation Research Board, National Research Council, Washington, D.C. 2003.

TABLE 4

REPORTED SPEEDS (MPH) ON CITY STREETS

City	Facility	Express	All Stop
Cleveland	Euclid Ave Median Arterial Busway		12 (1)
Los Angeles	Wilshire-Whittier Metro Rapid Ventura Boulevard Metro Rapid		14
Bogota Columbia	TransMilenio Median Arterial Busway	19	13
Curitiba Brazil	Median Arterial Busway System	19	12
Porto Alegre Brazil	Assis Brasil and Farrapos Median Arterial Busways		11-14
Quito Ecuador	Trolebus Median Arterial Busway		11-12
Sao Paulo Brazil	9 de Julho Median Arterial Busway		12
	Jabaquaro Median Arterial Busway		14

Source: Levinson, H., Zimmerman, S., et al, TCRP Report 90, Bus Rapid Transit, Volume 1, Case Studies in Bus Rapid Transit, Transportation Research Board, National Research Council, Washington, D.C. 2003.

TABLE 5

REPORTED TRAVEL TIME SAVINGS
BRT ON CITY STREETS

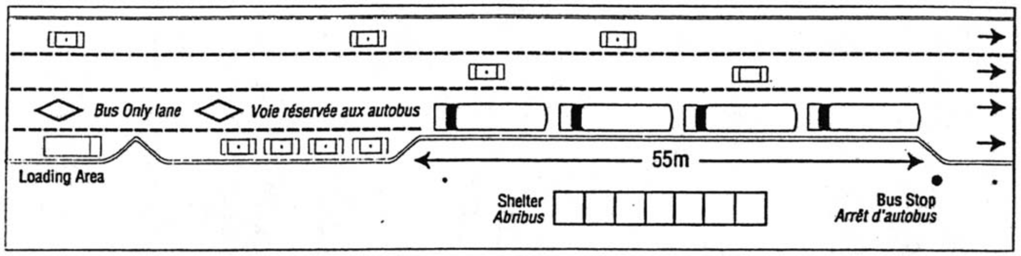
City	Facility	Travel Time (Min). Before	After	% Reduction	Travel Time Savings Total	Min/Miles
Cleveland[(1)]	Euclid Avenue Median Arterial Busway	41	33	20	8	1.2
Honolulu	City Express! (Phase 1)	35	20	43	15	2.3
Los Angeles	Wilshire-Whittier Metro Rapid	76	55	28	21	1.5
	Ventura Boulevard Metro Rapid	56	43	23	13	0.9
Vancouver	Broadway “B” Line				1.3 – 10	0.4 – 0.9
	Richmond “B” Line				10	1.0
Bogota	TransMilenio Median Arterial Busway			32		
Porto Alegre	Farrapos Median Arterial Busway	24	17	29	7	2.1

(1) Anticipated

Source: Levinson, H., Zimmerman, S., et al, TCRP Report 90, Bus Rapid Transit, Volume 1, Case Studies in Bus Rapid Transit, Transportation Research Board, National Research Council, Washington, D.C. 2003.

FIGURE 1

CONCURRENT FLOW INTERIOR BUS LANE
CENTRAL AREA OTTAWA



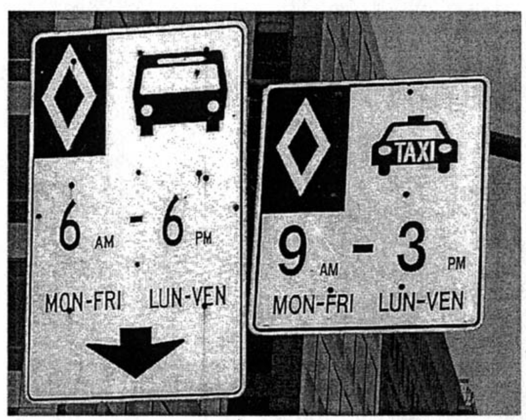
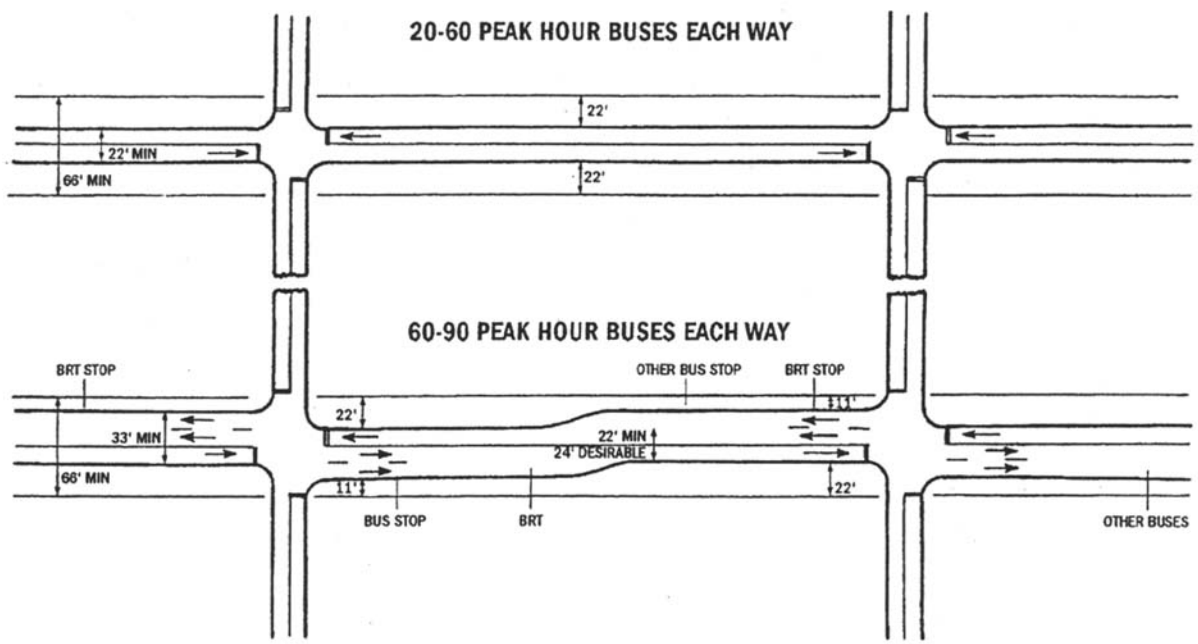


FIGURE 2

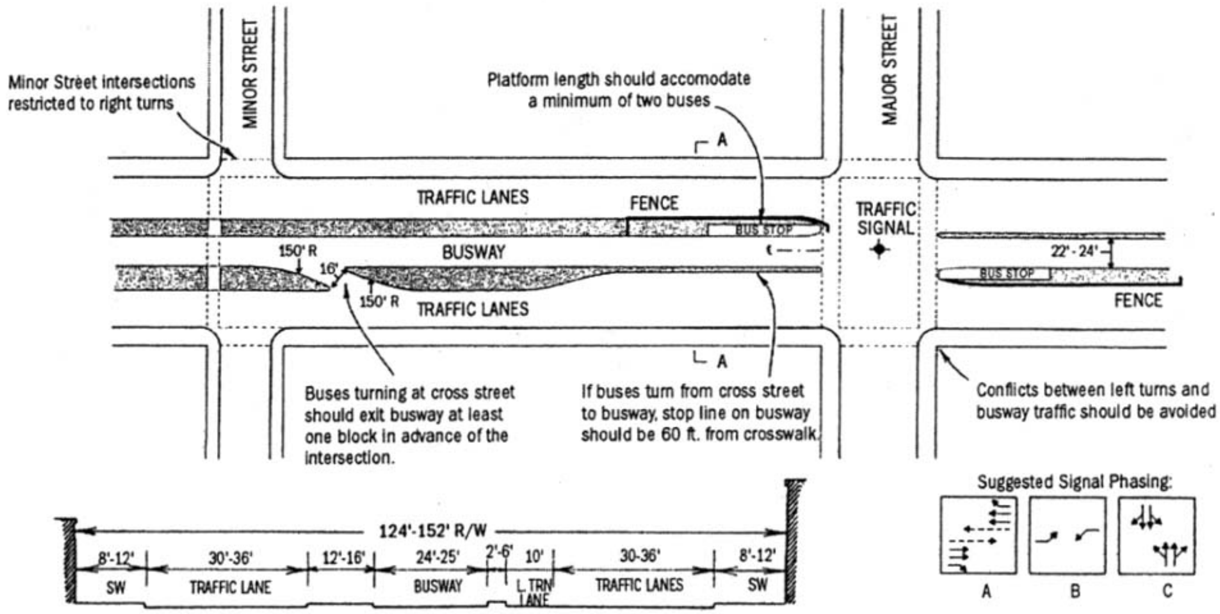
TYPICAL BUS STREET DESIGNS



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

FIGURE 3

ARTERIAL MEDIAN DESIGN FOR A WIDE ROADWAY



(Source: Adapted from Levinson, H., et al, *NCHRP Report 155 Bus Use of Highway - Highway and Design Guidlines.*)

FIGURE 4

TYPICAL MEDIAN ARTERIAL BUSWAY DESIGN

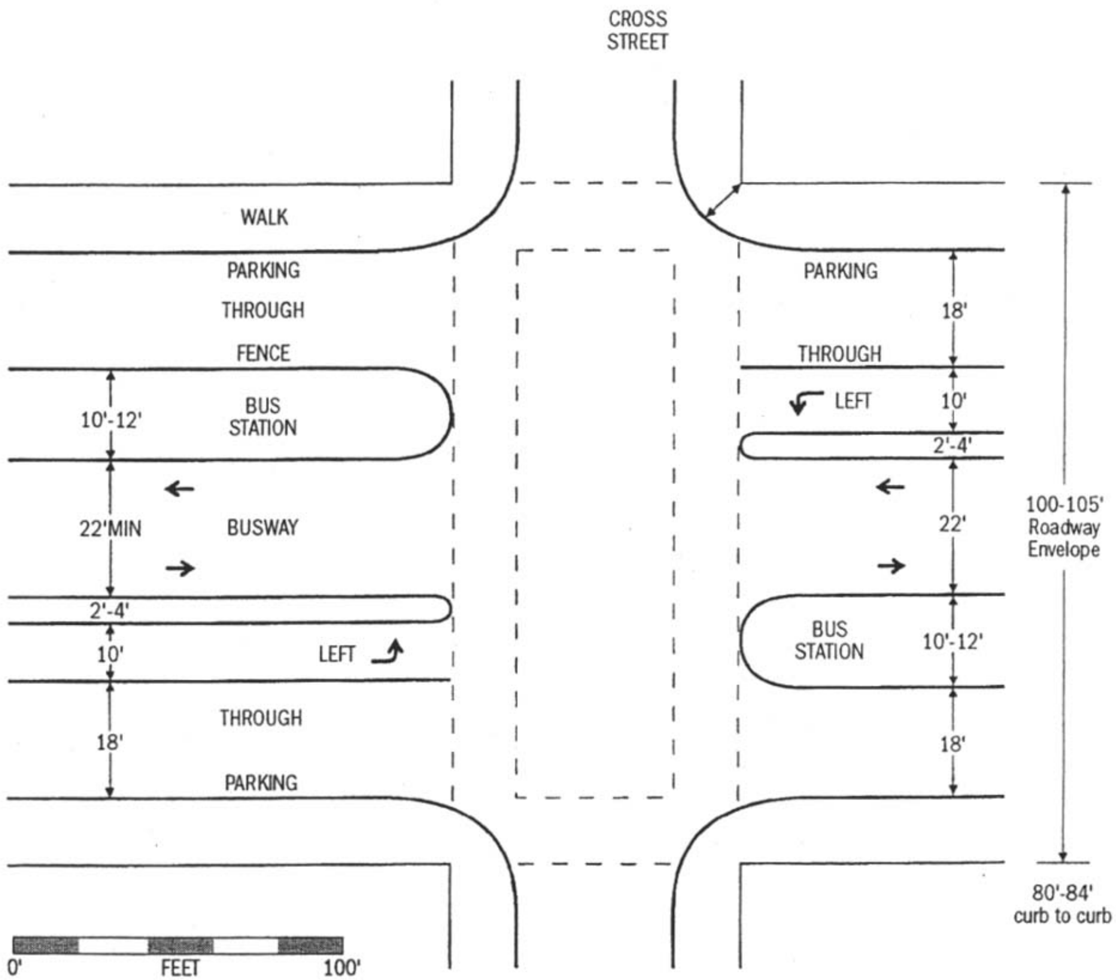
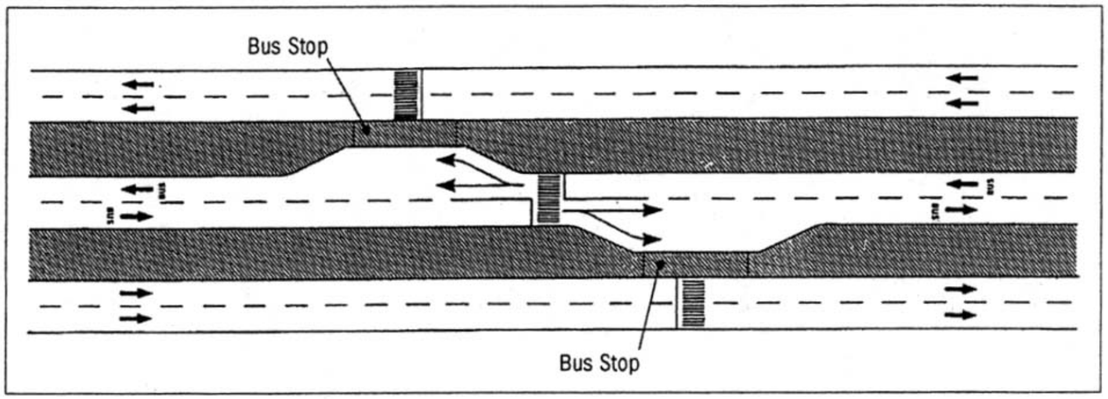
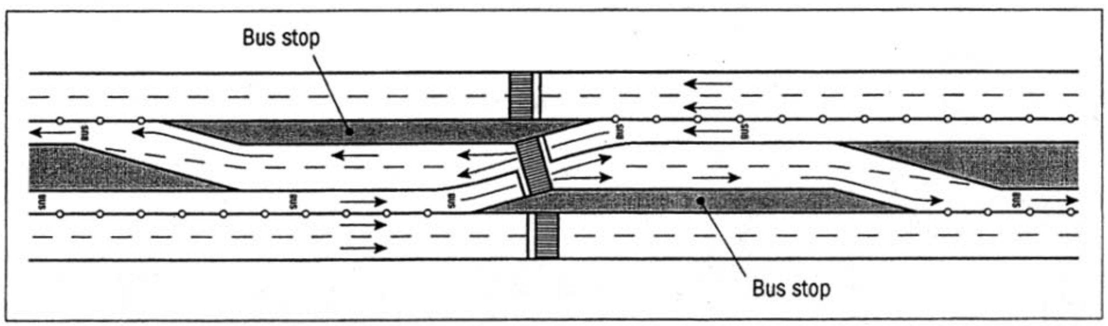


FIGURE 5

TYPICAL SOUTH AMERICAN MEDIAN ARTERIAL BUSWAYS



Typical Bus Stop Layout, Avenida Cristiano Machado, Belo Horizonte, Brazil



Typical Bus Stop Layout, Avenida 9 de Julho, Sao Paulo, Brazil

(SOURCE: Gardner, G., Cornwell, P., and Cracknell, J., *The Performance of Busway Transit in Developing Cities,* Transport and Road Research Laboratory, Drawthorne, Berkshire, U.K., 1991.)