SOUND TRANSIT

HCT Planning

Sound Transit Long-Range Plan Update

Issue Paper N.5: Convertibility of BRT to Light Rail

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Sound Transit

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FINAL

March 2005

Foreword

This issue paper is part of a series of reports designed to inform the Sound Transit Board in its decision-making on the Regional Transit Long-Range Plan update for the Sound Transit service area. Each issue paper provides information about a specific element or area of the Long-Range Plan and potential options. These reports focus on issues such as costs, ridership, engineering feasibility and operations.

The environmental impacts of the updated Long-Range Plan and Options, as well as potential mitigation measures, are examined in the Draft Supplemental EIS for the Regional Transit Long-Range Plan (December 2004). The Draft SEIS supplements the 1993 EIS prepared on the Regional Transit System Plan, and it generally updates that information and analysis through the year 2030. Public and agency comments on the 2004 Draft Supplemental EIS have been received and will be responded to in a final SEIS to be issued in June 2005.

The Sound Transit Board anticipates identifying a draft updated Long-Range Plan in the spring of 2005. There will be an opportunity for public review and comment on the draft Plan. The Board will adopt a final updated Long-Range Plan after public comments are received on the draft plan and the final SEIS is issued.

References in these reports to Sound Transit's existing Long-Range Plan are to the 1996 Regional Transit Long-Range Vision, which functions as the agency's Long-Range Plan. Discussion of the updated Long-Range Plan refers to the Plan being developed by Sound Transit over the coming months.

The following issue papers are being prepared:

<u>East Corridor</u>

E.1 – I-90 Corridor / East King County High Capacity Transit Analysis

<u>North Corridor</u>

N.1 – BRT in SR 99 Corridor

N.2 – I-5 Corridor Northgate to Everett HCT Assessment

N.3 – Seattle Streetcar Options

N.4 – SR 522 Corridor HCT Assessment

N.5 – Convertibility of BRT to Light Rail

<u>South Corridor</u>

S.1 – Tacoma Link Integration with Central Link

S.2 – Potential Rail Extensions to Frederickson and Orting

S.3 – HCT System Development Issues in the South Corridor

S.4 – Potential Tacoma Link Extension – West

S.5 – Rail between Burien and Renton

S.6 – Potential Tacoma Link Extension – East

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1. Introduction and Summary

1.1 Purpose

The purpose of this technical paper is to consider and discuss issues relating to incorporation of light rail transit (LRT) requirements into bus rapid transit (BRT) projects. The fundamental question to be addressed is:

> *Is it reasonable to develop BRT with the assumption that it can be converted to LRT in the future when demand will warrant a higher capacity or better performing system?*

The term "BRT" encompasses a broad range of service characteristics based on the spectrum of potential improvements which can range from low-cost priority treatments for buses to full grade separation. Conversion of a BRT facility that utilizes general purpose or high occupancy vehicle (HOV) lanes to LRT would entail certain policy decisions regarding the displacement of non-transit vehicles. In contrast, this paper generally focuses on what requirements need to be considered in the design of a busway-BRT type of facility for future conversion from BRT to LRT. This was undertaken by considering generic LRT requirements and what elements need to be incorporated into the civil and structural design of a BRT project to ensure modal flexibility in the future. Also, it was assumed that the BRT service operated on the facility would consist of a "trunk" service similar to rail service, with transfers to local feeder service, requiring a number of access points to the facility similar to that required for rail service.

A selection of BRT and LRT projects in the United States and overseas was considered to assess what the current industry practice is in relation to BRT conversion to LRT.

1.2 Key Findings

Conversion from BRT to LRT is a subject that has been studied and debated in cities across North America and Australia. Proponents of conversion point to the higher maximum carrying capacity offered by the larger LRT vehicles that can travel in trains of multiple cars, as well as the resulting lower operating costs due to the need for fewer vehicles and drivers. Detractors of converting to LRT assert that the capital costs associated with the conversion process outweigh any savings derived from lower operating costs, and that demand must be extremely high in order to reap those operating cost savings. Additional considerations include integration with the larger regional transit system, the ease with which transfers can be made between different modes, and the effect of different modes on land development. As of the writing of this paper, no known conversions have been made from BRT to LRT, other than the current project to convert the Downtown Seattle Transit Tunnel to joint bus and LRT use. Following are some of the key findings that were derived from a review of selected existing BRT systems:

- The majority of the BRT projects reviewed for this study include some provisions for future conversion to LRT. However, other than the current project to convert the Downtown Seattle Transit Tunnel, there are no known conversions from BRT to LRT.

- The arrangement of BRT cross sections varies considerably, and total width can vary from 20 to 54 feet. Lane widths range from 9.5 feet to 13 feet, with shoulders ranging from two feet to ten feet. Typical busway configurations include one lane in each direction with no physical barrier or separation between lanes. The total width required for two-track LRT is generally between 30 and 35 feet.

- The critical elements that must be considered for future conversion to LRT include the horizontal and vertical geometric constraints and the vehicle envelopes of both the BRT and LRT vehicles. LRT design constraints would generally control the design of a BRT project if future modal flexibility choices are to be accommodated.

- Issues to consider when deciding whether or not to convert a BRT facility to LRT include the relative capacity of the two modes compared with the existing and forecasted corridor demand, the need for larger terminal stations, the potential for lower operating costs with LRT, and the capital costs associated with conversion.

- The construction activities required for conversion vary depending on whether or not the BRT system was designed and constructed to include provisions for LRT. Such activities can include modification to both the mainline and to stations. If no provisions for LRT were included in the busway design and construction, the cost of conversion can be significantly higher due to the need for more extreme modification or total reconstruction of structures and other facilities.

2. BRT and LRT Case Studies

A study was undertaken considering several BRT and LRT projects from the United States and overseas. Summary information for each project considered can be found in Appendix A.

This comparison found that many of the BRT projects incorporated LRT design requirements during the planning and design phases. The extent to which LRT provisions are incorporated into design and construction is driven by the focus of the project (i.e., is it a project requirement to provide a separate piece of infrastructure for high capacity transit or simply a need to modify the existing system for bus priority).

The research indicated that there are several specific design elements that should be considered to ensure that the project has the flexibility to accommodate any possible technology conversion (e.g., bus to light rail). These include:

- Horizontal geometry (alignment);
- Vertical geometry (grades and clearances);
- Cross sectional width;
- Structural elements (including loading, pavement and stray current protection);
- Utility accommodation (both relocation, new services and drainage);
- Future guideway construction details to facilitate later removal and replacement with rail; and
- Further detail of each of these design elements and projects where these elements were adopted are discussed in Section 1.4.

Table 1 presents projects that provide a separate right of way for the mainline bus-only traffic, while Table 2 presents projects that incorporate the mainline bus movements with the general traffic (priority given in certain locations). Both tables indicate whether or not LRT provisions were included in the design and construction of the facility.

Table 1. BRT Projects with Bus - Only Right of Way

Projects	Existing / Proposed Projects	LRT Provisions
Adelaide (Australia)- O-Bahn	Existing	Yes Alignment criteria suitable for LRT.
Brisbane (Australia) - South East Busway and Inner Northern Busway	Existing	Yes The South East Busway has been designed for future conversion to light rail in sections: • A side tunnel stub was included in the original design in preparation for the introduction of light rail. This was to permit a future light rail alignment to access the busway along its alignment. • A vibration mat has been installed in one section where the busway alignment passes under a major hospital (Mater Private Hospital). Where possible, design elements required for LRT were considered for both projects. These include: • Clearance to structural elements • Some service relocations • Concrete pavement designed in the station areas, consideration of stray current
Boston, MA – Silver Line tunnel sections	Existing	Yes* The early designs for the Boston Silver Line (originally South Boston Piers Busway) were designed for conversion to LRT.
Curitiba (Brazil) – Curitiba BRT	Existing	Yes* Due to the expected capacity constraints on the bus system, a new monorail-based system is planned in one area.
Eugene, OR / Springfield - East West BRT	Proposed	No
Hartford, CT – The New Britain Hartford Busway	Proposed	Yes*
Jacksonville, FL – North Southeast	Proposed	Yes Horizontal and vertical alignment considered LRT requirements.

Projects	**Existing / Proposed Projects**	**LRT Provisions**
Busway		
Miami, FL – Dade Busway	Existing	N/A
Ottawa (Canada) – Ottawa Transitway	Existing	Yes Design provisions include vertical clearances, other elements of geometric design, and structural loadings to accommodate light rail vehicles.
Pittsburgh, PA – East / South and West Busway	Existing	Yes Some allowances for LRT included: • notches in the retaining walls for future catenary columns • additional weights / loadings of the track structure and revenue vehicles in the design of the roadway pavement slab and bridge structures. • additional horizontal and vertical clearances for the added track structure and LRV dynamic envelope, including OCS and side poles, span wires, mounting brackets, etc. • alignment (horizontal and vertical curves, grades etc.) • clearances are set to allow for light rail vehicles and the erection of centenary wires • underground structures are designed to accept light rail loadings
Seattle, WA – Seattle Bus Tunnel	Existing	Yes • adequate clearances for LRT vehicles were provided. • alignment (horizontal and vertical curves, grades etc.)
Sydney (Australia) – Liverpool Parramatta Transitway	Existing	Yes Design of the Transitway allowed for the conversion to light rail if demand warrants. Provisions include structures and grades to match light rail standards.

* Limited information available on the LRT components included

Table 2. BRT Projects with Bus and General Traffic or HOV Interaction

Projects	Existing / Proposed	LRT Provisions
Boston, MA – Silver Line (arterial sectrions)	Existing	Yes (early stages only) * The early designs for the Boston Silver Line (originally South Boston Piers Busway) were designed for conversion to LRT.
Cleveland, OH - Euclid Avenue BRT	Proposed	No Early stages planned for LRT; however, current design and operation plans would make it difficult for conversion.
Los Angeles, CA – El Monte Busway	Existing	Yes * • Aerial structures were designed to accommodate LRT El Monte busway was designed for eventual conversion, however, based on current operation it is unlikely that this will happen.
Las Vegas, NV – MAX	Existing	No
Vancouver (Canada) – Translink #98 & #99 B-Lines	Existing	No

* Limited information available on the LRT components included

Where the BRT system is in a central freeway median, the system has generally been shared with HOV traffic (e.g., the Los Angles El Monte Busway section between El Monte and Long Beach.)

Appendix A also presents two LRT projects that initially considered both BRT and LRT technology. Following initial planning, the locally preferred option chosen was LRT. These projects are:

- Sacramento – DNA Corridor AA Extension (Proposed LRT)
- Salt Lake City – North South CBD to University LRT (Existing LRT)

As can be seen from Table 1, most of the BRT-only facilities have incorporated the flexibility for future conversion to LRT. Consideration also should be given to how conversion would occur; e.g., how the remaining LRT components would be constructed while still maintaining public transit services. In some situations, the current operation of the busway makes it unlikely that conversion will occur without major disruption to transit service. Examples of this include the El Monte Busway in Los Angles and the Adelaide O-Bahn in Australia.

3. Comparison of LRT and BRT Vehicles

An understanding of the differences between light rail vehicles and buses is necessary to appreciate the elements of the design that are critical for flexibility if future modal conversion is to be considered. Throughout the United States there is currently a variety of BRT vehicles available and in use, ranging from the standard 40-foot transit bus and 60-foot articulated transit bus to the optical guided systems as used in Las Vegas on the Metropolitan Area Express. Table 3 presents the basic dimensions of BRT and LRT vehicles.

Table 3. Comparison of BRT Vehicles and LRT Vehicles

Dimension	Typical BRT Vehicle	Typical LRT Vehicle
Length	Large bus: 40 ft (12.1 m) or 35 ft (10.7 m) Articulated bus: 60 ft (18.3 m) Bi-articulated bus: 84 ft (24.5 m)	Articulated reversible LRV 55 ft (16.8m) to 95 ft (29m)
Width	8.5 ft (2.6 m)	8 ft (2.5 m) to 11 ft (3.4m)
Height	Large articulated bus: Approx 9.5 ft (2.8 m) Bi-articulated bus 11 ft (3.4 m)	Approx 12.5 ft (3.8 m) – this is approx height of roof mounted equipment above top of rail, (exclusive of catenary)

Lane Width Based on Vehicle Width

Generally, the standard lane width for non-guided BRT operation is recommended to be 11.5 feet. With a guided bus, it may be reasonable to reduce the lane even further depending on technology. If it is a mechanically guided bus, guide rails and curbs would be placed very close to the vehicle chassis. The inside clearance between the guide curbs will be approximately 8.5 feet in tangent sections. These “lanes” would need to be widened on any curve to address off-tracking (for both articulated and conventional buses).

Guided busway technology has been adopted on several projects and is planned for the Eugene BRT. Using guided buses minimizes the required clearances and therefore lane widths can be reduced. The proposed guided busway in Eugene would have a lane width of 10.5 feet. This is equal to the width of the bus measured between the outside edges of the mirrors. Optical and magnetic guidance systems have a certain amount of variance in their capabilities, on the order of +/- 6 in. As a result, a minimum bus lane of 9.5 feet would be recommended on tangent sections. However, to account for the dynamic envelope and the bus mirrors, the width is still dictated by an envelope for the bus of approximately 10.5 feet to avoid knocking mirrors off of the buses when they pass (Adelaide O-Bahn had an adopted lane with of 9.5 feet with 1 foot 4 in separation between the roadways).

Light rail vehicles are wider than buses and require a wider envelope in which to operate. Typically the design envelope is 30-35 feet wide for LR vehicles (two directions), including required horizontal clearances and width for overhead catenary poles. The required width is typically wider in locations of walls, bridges and tunnels. Therefore, in the case of designing a corridor to upgrade to light rail in the future, the dynamic envelope of the light rail vehicle will generally control the design (further discussed in Section 5). However, the inclusion of passing lanes and wide shoulders can result in a busway that exceeds the standard width of an LRT alignment.

Speeds

Vehicle speeds are dependent on the route selection, design speeds and type of vehicle. Some of the current articulated buses may have lower acceleration rates and lower maximum speed capabilities than typical LRT vehicles. Also some types of guided buses have limited speeds.

Capacity

BRT systems typically use smaller capacity vehicles than LRT. LRT achieves higher capacity by operating larger vehicles or operating in trains two to three or more cars in length.

LR vehicles generally also have the following properties:

- Electric propulsion using overhead electrification,
- Reserved right of way operation on ballasted or embedded track, and
- Low floor vehicles with multiple doors and doorway floors at the same level as station platforms (this is more typical of new systems; many older LRT systems still use high-floor vehicles that do not facilitate level boarding).

Another factor to consider is disability access requirements. Americans with Disabilities Act (ADA) requirements are typically met with LRT vehicles. BRT also can be managed such that these requirements are met by using low-floor vehicles, mechanical lifts, ramps and providing wheelchair securement on board.

4. BRT and LRT Operating Configurations

The operational requirements of the busway will drive the cross section configuration. The following figures illustrate the variation in cross sections that have been developed at a variety of systems, as well as standard LRT cross section widths.

4.1 Guided Busway

Figure 1 illustrates the minimum cross section that can be adopted for a guided busway. Depending on the type of guidance system adopted, the allowances in the lane width vary slightly. Figure 3 below is based on the typical cross section for the Adelaide O-Bahn which has lateral guide rails. Guide rollers are directly connected to the steering knuckle of the bus and move along the lateral guide rail. Due to the controlled environment, the track width (lane width) is only slightly larger than the vehicle width.

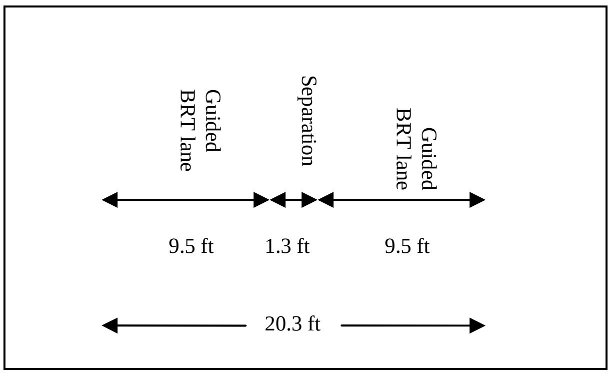
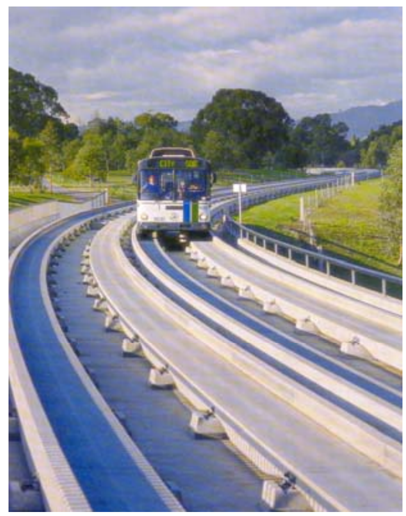


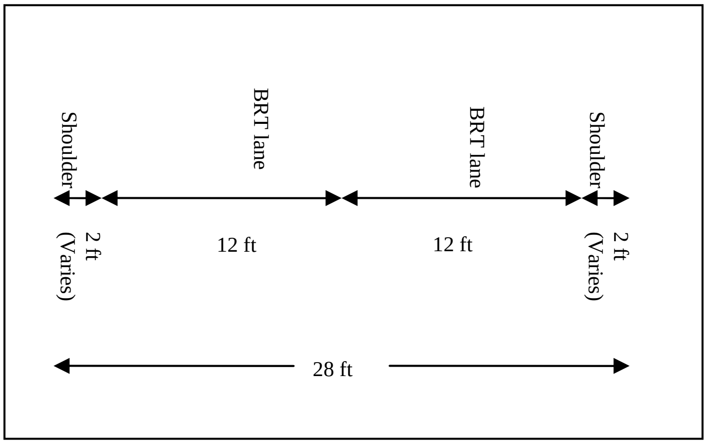
Figure 1. Guided Busway (e.g., Adelaide, Australia)



Adelaide, Australia O-Bahn

4.2 Typical Busway

Figure 2 below illustrates a standard cross section that has been adopted on several of the projects that are summarized in Table A (see Attachment 1). The bus lane width may vary from 10.5 feet to 12 feet and the shoulder width varies from approximately 2 feet to 10 feet. This cross section configuration, with a bus lane in either direction does not allow for a bus to pass a possible broken down bus on the main route without the passing bus crossing into the opposing lane. The BRT projects that have this configuration on the main alignment have adopted passing lanes through the station areas to allow for express buses to pass the standing "all stops" services.

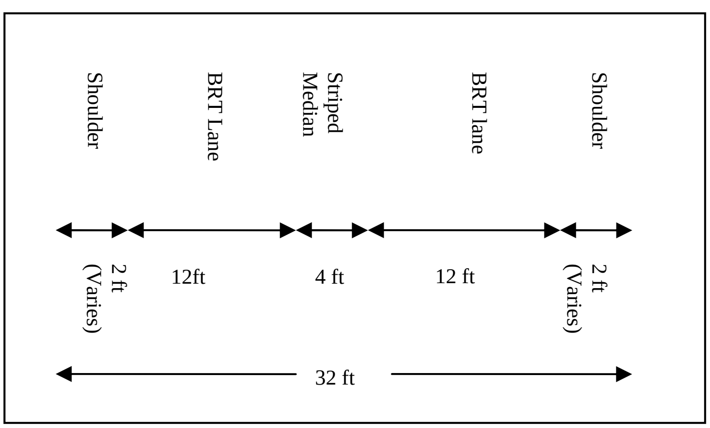


Pittsburgh, PA Busway

Figure 2. Busway (e.g., Pittsburgh, PA)

4.3 Busway with Wide Median

Figure 3 below illustrates a standard lane configuration for the main alignment of a busway with a wide median. Depending on the width of the median and shoulders, this cross section configuration allows for a bus to pass a possible broken down bus without completely crossing into the opposing lane. Similar to the typical busway configuration, this configuration includes passing lanes through the station areas to allow for express buses to pass the standing "all stops" services.



Miami, FL Busway

Figure 3. Busway with Wide Median (e.g., Miami, FL)

4.4 Barrier-Separated Busway with Shared ROW (BUS and HOV)

Figure 4 illustrates the extent of width and separation allowances that have been made when HOV traffic and bus traffic are using the same facility (e.g., the Los Angles El Monte Busway). Barrier separation between the two carriageways is needed as the vehicle volumes using the facility are generally higher and the speed environment is also generally high. Allowances need to be made for the HOV (first time driver) and the unpredictability in traffic, in the lane and shoulder widths. Passing of a broken down vehicle would be possible if the vehicle pulled into the shoulder area.

Los Angles, CA El Monte Busway

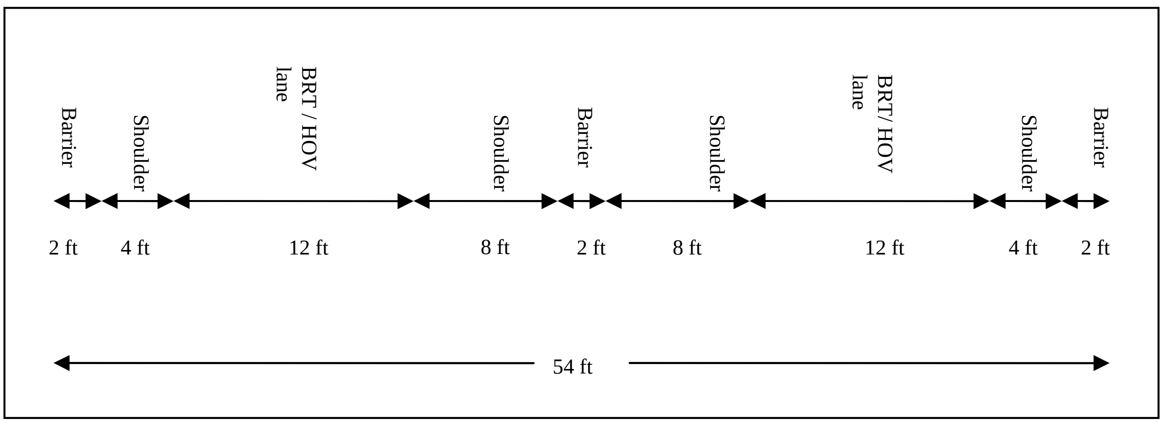


Figure 4. Barrier Separated Busway for HOV and Bus traffic (e.g., Los Angles, CA)

The safety operations plan that is developed for BRT projects operation reflects the cross sectional allowances adopted. The tighter the cross section (i.e., the narrower the shoulders and lane width), the more rigorous the safety operation plan needs to be with regard to speed of the transit vehicles, condition of the fleet and clear distinction on when a bus is allowed to pass another bus on the main alignment.

4.5 At-grade LRT

Figure 5 shows the typical minimum cross section width required for at-grade LRT with two tracks running side by side.

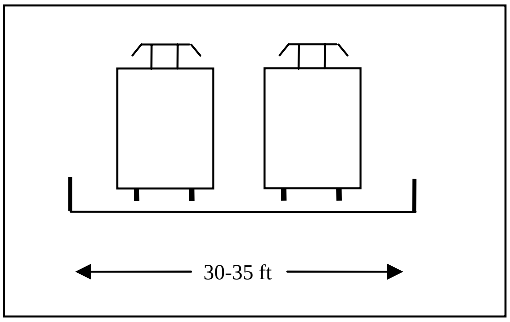


Figure 5. At-grade LRT (e.g., San Diego, CA)

San Diego, CA LRT

4.6 Elevated LRT

Figure 6 shows the typical minimum cross section width required for elevated LRT with two tracks running side by side. Approximately 10 feet is required at ground level; the track can be cantilevered over roadway or other adjacent uses.

Pittsburgh, PA LRT

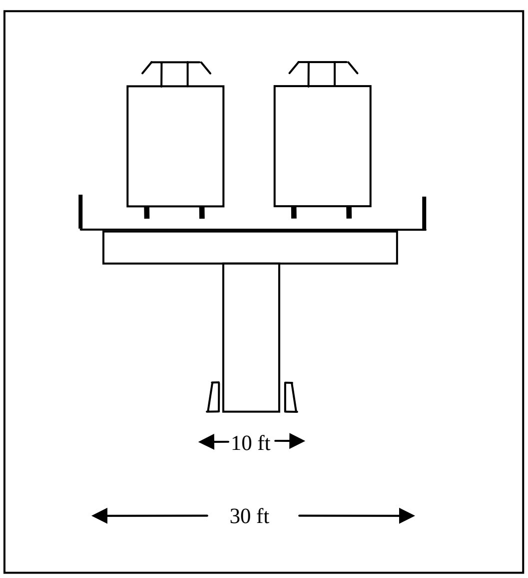


Figure 6. Elevated LRT (e.g., Pittsburgh, PA)

4.7 Below-grade LRT

Figure 7 shows the typical minimum cross section width required for below-grade LRT with two tracks running side by side.

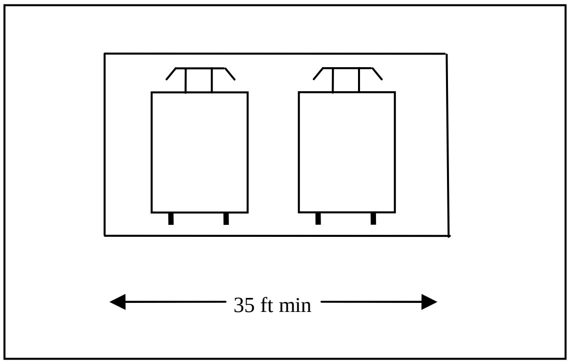


Figure 7. Below-grade LRT (e.g., St. Louis, MO)

St. Louis, MO LRT

5. Design Elements for Future LRT Conversion

Several key criteria have been incorporated in BRT projects where possible to ensure future LRT conversion. Design elements can be broken down into several key areas:

- Horizontal geometry (alignment);
- Vertical geometry (grades and clearances);
- Cross sectional width;
- Structural elements (loading, pavement and stray current protection);
- Utility accommodation (relocation, new services and drainage); and
- Future guideway construction details to facilitate later removal and replacement with rail.

Of the BRT right-of-way-only projects (see Table 1) that considered future LRT, generally the horizontal and vertical geometric constraints of an LRT vehicle and the vehicle clearance envelopes were considered. If possible future modal conversion is a requirement of the project, these elements are critical, to ensure that major reconstruction of the route is not necessary in the future. The extent of concrete pavement and utility relocation that was undertaken in these projects to suit LRT varied from project to project.

Review of LRT design parameters and several of the BRT design parameter reports indicated that the following elements should be considered for BRT projects if conversion to LRT in the future is a possibility. Consideration of these elements ensures long term flexibility of the infrastructure.

The following table details the typical design elements for a BRT project where LRT constraints need to be considered and whether BRT or LRT requirements control the design.

Table 4. Controlling Design Elements BRT and LRT

Design Element	BRT Controlling	LRT Controlling
Design Speed (Varies depending on alignment)	√	√
Horizontal Geometry		√
Vertical Geometry		√
Gradients		√
Superelevation		√
Horizontal Clearances		√
Vertical Clearances		√
Platform		√
Pavement		√
Stray Current Protection		√
Utility Accommodation		√
Cross Section (Varies depending on the vehicle type)	√	√

Design Speed for BRT and LRT

General design speed should be compatible for both vehicles.

Horizontal and Vertical Geometry

Horizontal and vertical geometry should be driven by the LRT requirements. Generally the horizontal and vertical curves should be calculated based on stopping sight distance requirements for light rail vehicles on the basis of the LRT service braking rate[1]. Approach curves to station platform areas should consider the LRT vehicle. It is preferable for both the LRT and BRT vehicle that station areas do not include curves.

The combination of vertical and horizontal geometry is critical for LRT alignments.

Gradients

A maximum desirable gradient of 7% is typical and should be assessed for LRT vehicle performance. The gradients through stations are driven more by accessibility and structural requirements.

Cant / Superelevation

Tighter constraints on the superelevation criteria exist for LRT alignment than for BRT alignment. The superelevation should be assessed in terms of “balance”, “comfort” or “limit” design criteria for LRT vehicles. Rates of transition also should be considered for the LRT vehicle.

Vertical and Horizontal Clearances / Cross Sectional Requirements

LR vehicles are wider then buses and therefore require a wider envelope to operate in. The LR vehicle clearance envelope is critical in determining the alignment envelope necessary. The Developed Kinetic Envelope (DKE), also known as the swept envelope allows for the effects of vertical and horizontal geometry. DKE determines the clearances necessary for the median, retaining wall, tunnel wall, etc. The clearance should be approximately 2 feet (0.6m); however, this varies depending on whether the system is open air, in a deep cutting, or tunnel.

The Static Envelope is based on the LR vehicle at rest on level track and is used to determine the distance from the platform edge to the vehicle door threshold (approximately 1.5 in (40mm) depending on the vehicle and future rail position).

Vehicle clearances required for the LRV need to consider the top of finished rail level to catenary fixing requirements. This is critical for clearances under structures (e.g., bridges).

Generally, all clearances determined have to consider any superelevation, and incorporate any necessary clearance to top of rail.

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[1] LR vehicles service braking rate is approximately 59 in/sec^2 (1.5 m/sec^2)) the maximum emergency deceleration rate of 106 in/sec^2 (2.7m/sec$^{2)}$ should be used in emergency situations.

Platform Dimensions

Ideally, platform construction for the BRT should be LRT compatible, in order to save substantial future costs in providing a station suitable for the LR vehicle. Elements to consider are vehicle height, width and length.

Platform height to suit the LR vehicle disability access could be provided later by raising the end of the platforms to suit, and if the full length of the platform is not proposed for the BRT then provisions should be allowed for future extension to the platform.

Ideally the minimum platform crossfalls should be chosen. This assists with the architectural finishes, clearances to structures and disability access.

Pavement

Any concrete pavements constructed for the BRT should consider the possible LR vehicle axle loads (approximately 13 tons), how and where the rail will be installed and consideration to stray current protection.

There are two possible options for the BRT concrete pavement levels that will still provide for future LRT conversion. The first is to allow for the future rail pockets to be cut into the pavement, and the second is that a slab be overlaid to allow for the formation of the rail slots.

Rail drainage also should be considered in all concrete pavements that are constructed for dual usage (BRT and LRT).

Stray Current Protection

To prevent electrolytic corrosion of adjacent structures, foundations and services, stray current protection will be necessary to any elements that are to be utilized if LRT proceeds (including the concrete pavement reinforcement).

At-Grade Intersections

Consideration of the swept path for the LR vehicle and other vehicle movements at intersections should be considered during design. Location of future LRT points should be considered and they should not be located in pedestrian areas or areas of with a heavy volume of crossing traffic.

Utility Accommodation

All existing utility relocation should consider the future LRT infrastructure. The proposed BRT drainage system should consider how the future LRT infrastructure is going to be incorporated. Consideration of the rail drainage, point drainage and how the underground LRT infrastructure will be drained are some of the issues to consider during the design phase.

6. BRT to LRT Conversion

6.1 Has it Been Done?

The current project to convert the Downtown Seattle Transit Tunnel (DSTT) to joint bus and LRT use is the only known conversion project at this time. The conversion, which is scheduled to begin later in 2005, is required to accommodate the implementation of ST's Central Link project.

Plans to convert the DSTT from its initial bus operations to future rail transit use began in the mid-1980's during the design of the DSTT. Major rail transit design elements that were included in the construction of the DSTT were:

- Rail transit horizontal and vertical geometry requirements,
- Tunnel clearances for light rail vehicles,
- Platform lengths in all stations to accommodate 4-car LRV consists,
- Station capacity to accommodate LRT ridership projections, and
- Sizing of structural elements to support light rail transit loads

Incorporating these elements in the original construction has minimized the amount of demolition and reconstruction of the DSTT required to convert to LRT use. A major part of the work that will occur during the conversion of the DSTT in 2005 and 2006 is required to incorporate the new LRT traction power system. Platform and track modifications will also occur to allow use of low-floor LRV's. Fire/life safety systems will be upgraded and train signal and control systems will be incorporated.

When the DSTT conversion is completed, buses and light rail vehicles will operate jointly through downtown Seattle.

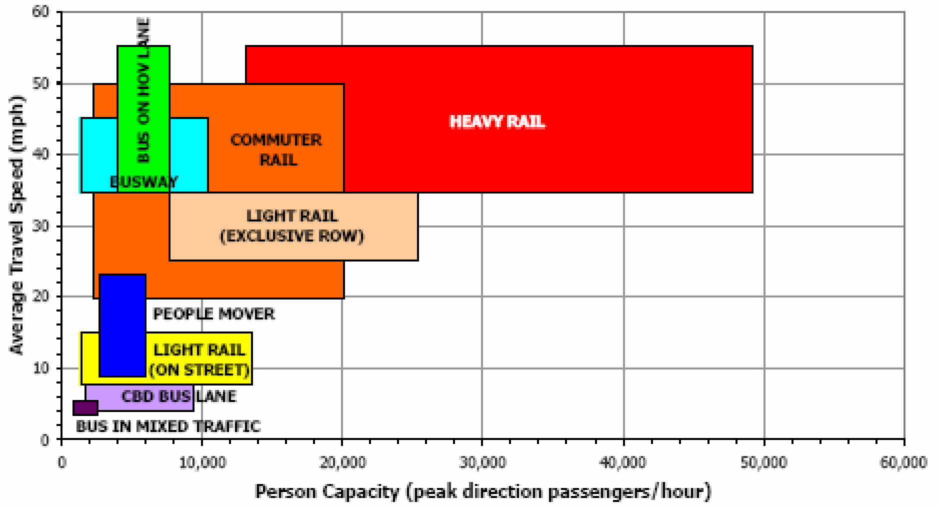
6.2 When to Convert – Issues to Consider

Conversion from BRT to LRT is a subject that has been studied and debated in cities across North America and Australia. Proponents of conversion point to the higher maximum carrying capacity offered by the larger LRT vehicles that can travel in trains of multiple cars, as well as the resulting lower operating costs due to the need for fewer vehicles and drivers. Detractors of converting to LRT assert that the capital costs associated with the conversion process outweigh any savings derived from lower operating costs, and that demand must be extremely high in order to reap those operating cost savings. Additional considerations include integration with the larger regional transit system, the ease with which transfers can be made between different modes, and the effect of different modes on land development. As of the writing of this paper, no known conversions have been made from BRT to LRT, other than the current project to convert the Downtown Seattle Transit Tunnel. Therefore, any discussion of thresholds for determining when to convert from BRT to LRT is purely hypothetical, and would depend a great deal on the specific characteristics of the corridor in question, including existing and future land use patterns and growth. The section below discusses some of these issues in more detail.

Capacity and Demand

The capacity of BRT and LRT can be influenced by vehicles, stations, and service frequencies, among other factors. The more exclusive forms of BRT share most of the functional characteristics of LRT, including capacity levels. LRT achieves a higher maximum capacity than BRT by operating larger vehicles in trains. BRT vehicles have lower capacity than LRT but can operate at higher frequencies, since multiple buses can be stopped at a station simultaneously, depending on station length.

There is no exact point or ridership threshold at which a BRT system should be converted to LRT. As shown in Figure 8, there is considerable overlap in the capacity that can be achieved by various modes. The capacities shown in the figure give some indication regarding the magnitude of demand that may be appropriate for considering a conversion to LRT. Also, conversion to LRT should be considered prior to the point where demand approaches capacity on the BRT system, which can result in vehicle bunching and passenger delay.



Source: TCRP Report 100, Transit Capacity and Quality of Service Manual, 2nd Edition, Transportation Research Board 2003.

Figure 8. Typical Travel Speed and Capacity Ranges of North American Transit Modes

Terminal Stations

As transit demand increases in a particular corridor, BRT service can be increased to meet that demand through increasingly higher frequencies. This should not be a problem at in-line stations, assuming that a passing lane is provided in station areas and bus dwell times are kept to a minimum. However, at terminal stations, an increase in the frequency of bus arrivals and departures, combined with increasing layover space requirements, can result in an eventual need to significantly upgrade the terminal facility. An extreme example can be found in New York City, where the bus-only lane on the approach to the Lincoln Tunnel carries over 32,000 passengers per hour during the peak period in the peak direction and leads directly to the Port Authority Midtown Bus Terminal with over 200 bus bays. The cost of acquiring the property for such a bus facility, in addition to constructing it, may be prohibitive in many cities. At such a point, it may make more sense to convert the line to LRT rather than invest any more money in upgrading BRT facilities.

Operating Costs

As mentioned earlier, the fact that LRT utilizes larger vehicles operating in trains can result in lower operating costs when compared to BRT. However, such operating cost savings can only be achieved when a certain passenger demand is exceeded. Such a threshold is difficult to determine because the service levels of BRT and LRT systems vary depending on the specific application.

Capital Costs

Another issue to consider is the expected rate of growth in demand for the transit service. If the demand that may justify an LRT alternative is reached quickly, it may be less expensive not to first implement BRT and then convert to LRT, saving the conversion cost. Funding sources for capital costs may be different from those available for operation and maintenance costs, and these differences may affect the long term cost advantages of each alternative.

6.3 Conversion Steps

Although most of the BRT running way designs allow for possible future conversion to rail transit, at the time this report was prepared there were no known completed conversions of busways to LRT, outside of Seattle.

Several existing BRT systems are currently being studied for possible extensions or modifications to increase the capacity of the transit facility. The transit authority in Curitiba, Brazil is currently studying replacement of buses with "electric tramcars" on two of the busiest busways.

Conversion from BRT to LRT can be looked at from two perspectives:

1. BRT systems that were designed and constructed with provisions for future conversion to LRT.
2. BRT systems that do not include any LRT provisions.

The amount of disruption to the operating BRT transit system during conversion varies greatly and needs to be a policy decision during the design stage of the BRT. At the BRT design phase, decisions on how to address the following items will influence the level of disturbance to transit services at the time of conversion:

- The extent to which LRT provisions (as discussed in Section 5) are included in the BRT design and construction;
- Whether or not the system is at-grade or on elevated structure and ease of access to the guideway;
- Availability and access to the work sites which will influence how the rail and supporting infrastructure can be installed; and
- How the LRT conversion project is procured and delivered, and whether or not the contractor is required to maintain access to the guideway.

Conversion from BRT to LRT when LRT Provisions were Included

Where BRT infrastructure has been developed to incorporate the basic functional requirements for conversion to LRT, the conversion could be carried out as a series of steps designed to minimize the impact on the operating transit system. Assuming that a moderate level of BRT service shut-down is acceptable and that all LRT design considerations discussed in Section 5 were considered, the following construction activities would generally be required for conversion to LRT (listed construction activities do not necessarily have to occur in order):

Mainline

- Establish alternative routes (or possible procedures for buses to utilize the same transitway with traffic control) for the existing bus services using the BRT infrastructure to establish required work area. Work area size will be dictated by LRT rail installation requirements. It may be necessary for buses to use the local road network for segments of the route. This can be minimized if access and exit points from the local road network to the separate BRT facility can be established.
- Relocate additional utility as required.
- Pavement modification as required (varies depending on whether ballasted track or concrete pavement with direct fixation track will be adopted).
- Rail infrastructure installation.
- Overhead catenary system installation (unless one of the emerging technologies for in-guideway electrification is implemented).
- LRT system and signaling installation.
- Drainage modifications as required. Underground buried equipment and rail drains to drain to the established BRT drainage system.

Stations

- Assuming that the station includes a four-lane cross section with platforms on either side, ensure that the LRT work sites only occupy one platform at a time. Only one bus direction at a time would then be impacted. Establish alternative route for the impacted bus direction and suitable passenger disembarking location. It may be possible for the unaffected platform to be used as a center platform; however, safe pedestrian paths of travel must be maintained. It may also be necessary for temporary signals to be installed or additional pavement constructed.
- Modification to the platform height to allow for disabled access to the LRT vehicle and modification to platform length if required.
- Additional utility relocation as required.
- Pavement modifications as required.
- Rail infrastructure installation.

- Overhead catenary system installation.
- LRT system and signaling installation.
- Drainage modifications as required. Underground buried equipment and rail drains to drain to the established BRT drainage system.

At a time when demand is high enough to justify the conversion, it would be advantageous to minimize the length of time that the system is out of service. Construction of suitable pavement and possibly even rail installation in the busway in parts, providing the necessary insulation for stray currents, and relocating necessary utilities at the time of the busway construction can significantly simplify and streamline the conversion process.

Conversion from BRT to LRT when LRT Provisions were not Included

The cost and time needed to convert a busway that was designed only for bus operations to LRT may outweigh the benefits of implementing a rail system, particularly if the project requires substantial structures (e.g., bridges and tunnels) to be reconstructed. Particularly in urban areas, it may be possible to insert a busway into a geometrically constrained environment that is not suitable for LRT because of the required vertical and/or horizontal curves. Therefore, while the list of construction activities required for conversion to LRT may be similar to those listed above, the total cost of conversion could be much higher, since the activities may require much more extreme modification or even total reconstruction of structures and other facilities to meet LRT requirements.

7. Key Findings

The case studies reviewed indicated that the majority of BRT projects are considering or have considered future conversion to LRT. However, no BRT projects have yet been converted to LRT, though conversion of the Downtown Seattle Transit Tunnel will soon be underway. The LRT requirements incorporated into the design and construction of BRT projects varied from only considering the horizontal and vertical geometric constraints of LRT to incorporating underground Y-Junctions for future LRT alignments.

Vehicle type (LRT, bus, guided bus) must be considered when determining the typical cross section for a project. For example, the minimum guided busway cross section is smaller than the typical LRT cross section. However, for a standard bus, once lane widths, shoulder requirements and possible passing lanes are considered, the cross section can exceed the LRT requirement.

The arrangement of the BRT cross section for the projects reviewed varied considerably. Lane widths ranged from 9.5 feet to 13 feet, with shoulders ranging from 2 feet to 10 feet. The systems that utilized buses generally had only one lane in either direction with no physical barrier or separation between the lanes. The cross sections widened to incorporate passing lanes in the station areas. The BRT systems that were utilized by buses and general traffic (HOV) incorporated physical separation between the lanes and significantly wider shoulders.

Case studies of LRT projects were not carried out specifically for this report. However, investigations were undertaken to determine the standard cross sectional width allowance for LRT. It was found that typical LRT cross sections do not vary as much as for BRT. The spacing between the tracks is determined by the vehicle width, clearances to structure, and the width of any emergency walkways between the vehicles. Minimum spacing from center of track to center of track is approximately 16 feet. Two-track (one in each direction) LRT generally requires between 30 and 35 feet.

Several key design issues were identified for consideration in a BRT project to incorporate the necessary elements for future conversion to LRT. The critical elements that need to be considered are the horizontal and vertical geometric constraints and the vehicle envelopes of both the BRT and LRT vehicles. LRT design constraints would generally control the design of a BRT project if future convertibility is desired.

Finally, conversion from BRT to LRT is a controversial issue that has been debated in many cities. Issues to consider in the decision-making process include the relative capacity of the two modes compared with the existing and forecasted demand in the corridor, the need for larger terminal stations, the potential for lower operating costs with LRT, and the capital costs associated with conversion. The construction activities required for conversion vary depending on whether or not the BRT system was designed and constructed to include provisions for LRT. Such activities can include modification to both the mainline and to stations. If no provisions for LRT were included in the busway design and construction, the cost of conversion can be significantly higher due to the need for more extreme modification or total reconstruction of structures and other facilities. Also, provisions should be made to accommodate continuation of existing bus service during construction.

8. References

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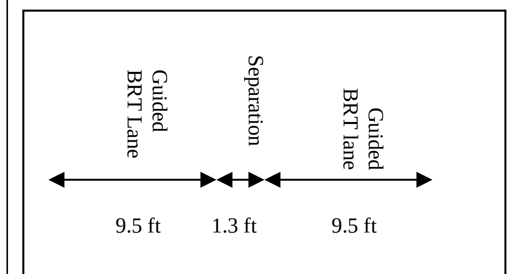
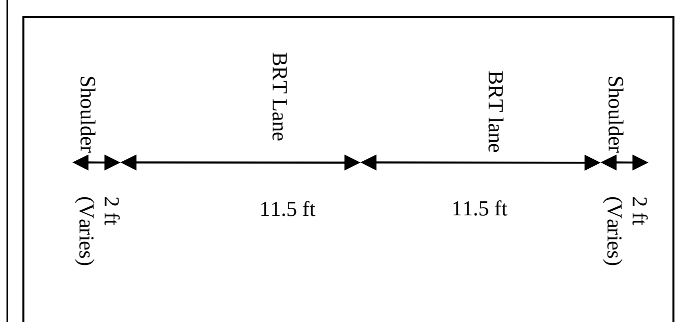
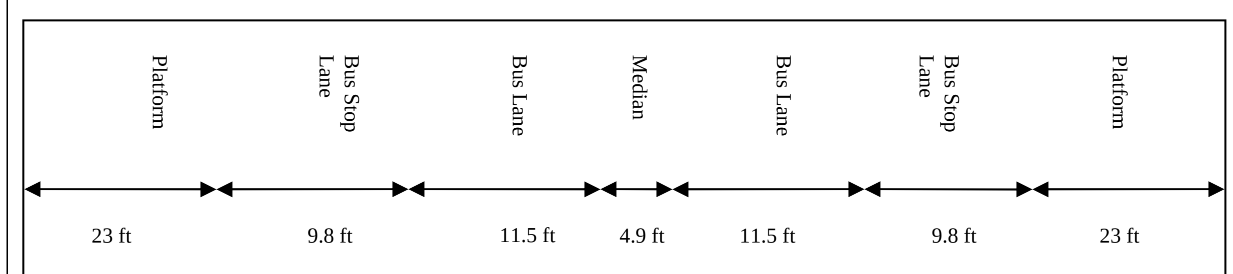
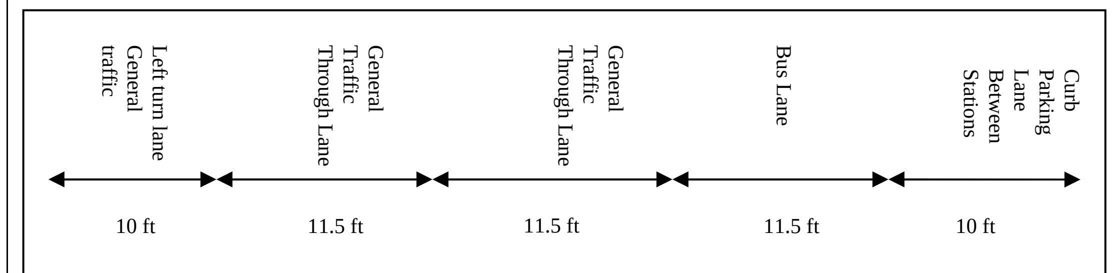
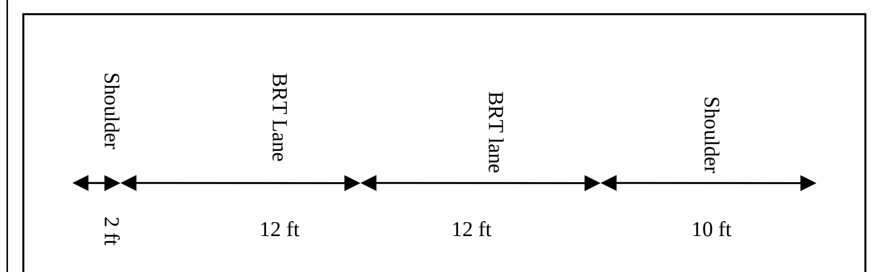
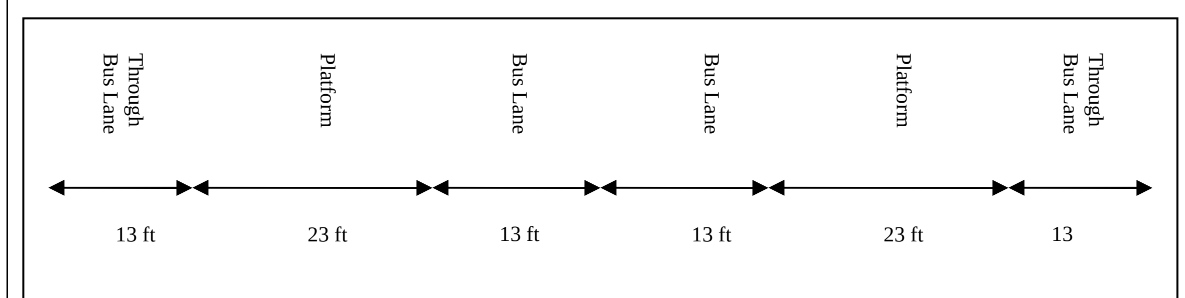
TCRP Report 100, *Transit Capacity and Quality of Service Manual*, 2^{nd} Edition, Transportation Research Board 2003.

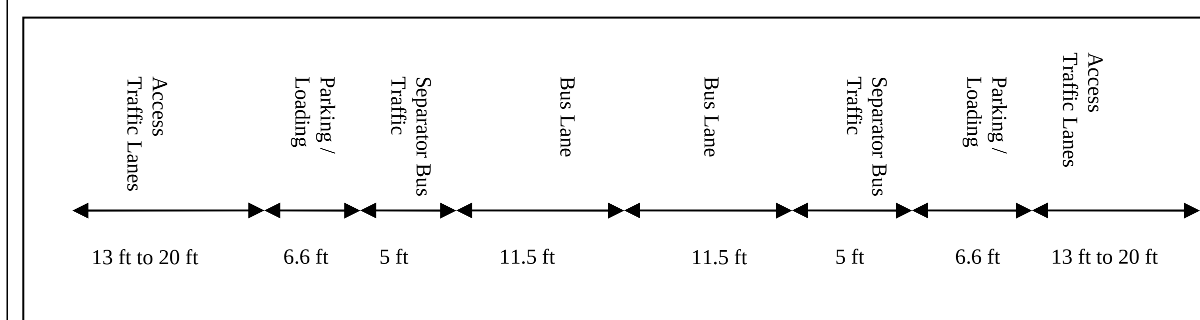
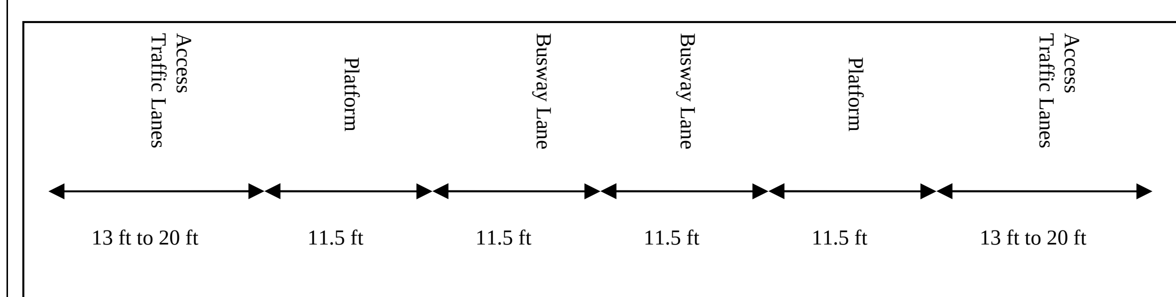
TCRP Report 90, *Bus Rapid Transit Volume 1: Case Studies in Bus Rapid Transit*, Transportation Research Board 2003.

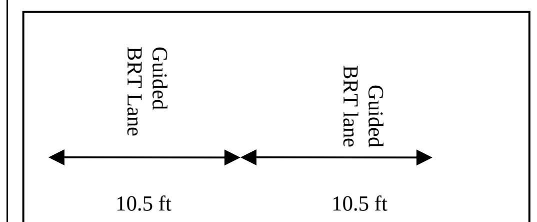
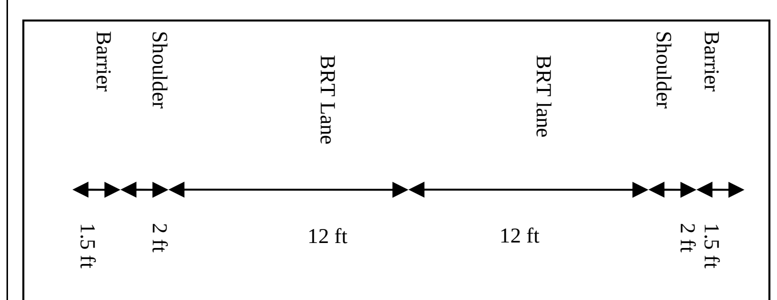
TCRP Report 90, *Bus Rapid Transit Volume 2: Implementation Guidelines*, Transportation Research Board 2003.

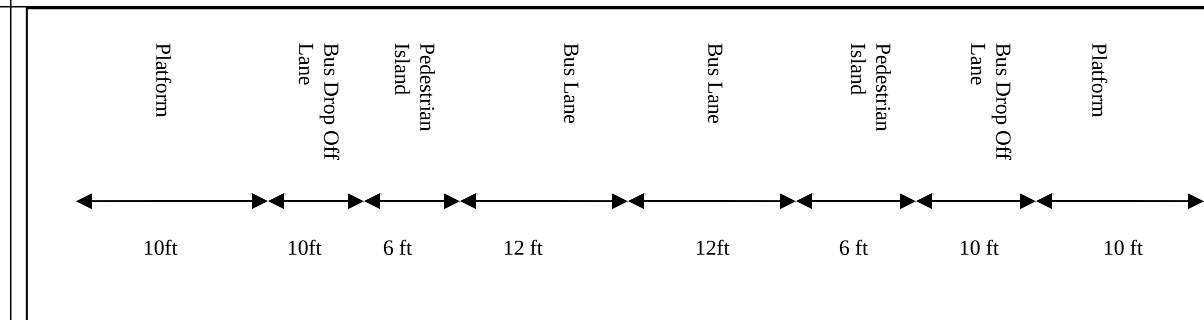
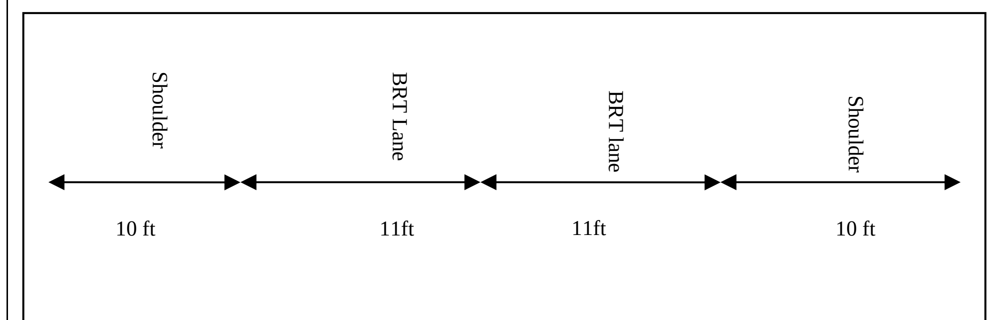
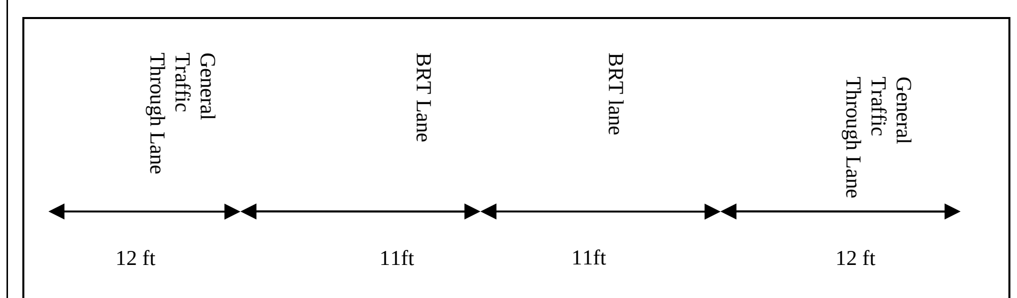
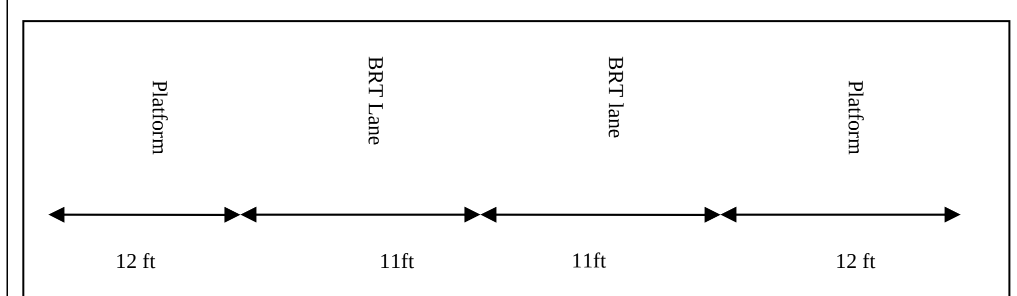
Appendix A: Summary of BRT / LRT Related Projects

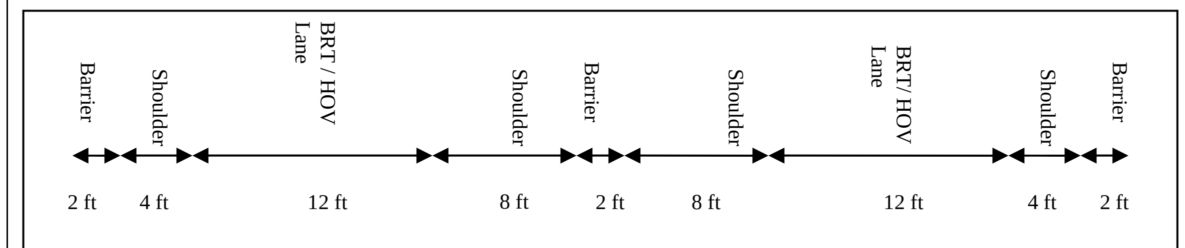
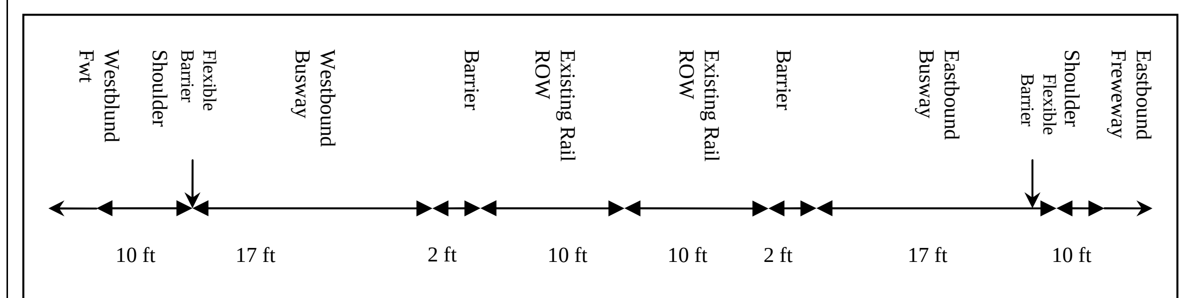
Category	Project Name	Location	Project Description	LRT Conversion Possible (Y or N) Allowances made in Design	Cross Section Available
Existing BRT only (Original planning was LRT system)	Adelaide O-Bahn	Adelaide (Australia)	The 12 kilometer (7.5 mi) O-Bahn in Adelaide is the largest full-scale operational guided busway in the world and was the first Bus Rapid Transit system in Australia. The Northeast O-Bahn was opened in two stages, in 1986 and 1989. Operating within the narrow landscaped land corridor of the River Torrens Linear Park, the Adelaide O-Bahn requires significantly less physical space than conventional busways. Buses run at about 100 kilometers (62 miles) per hour with limited stops. Similar to a rail system, buses arrive frequently—approximately every 20 to 30 seconds during the height of peak hours. The average headway is 50 secs over the peak due to bunching and randomness in bus arrival times, buses do in fact operate at 20-30 second headways at the peak of the peak - this has been confirmed by observation. During inter-peak periods, buses operate at 5 minute headways. One advantage of the O-Bahn compared to rail is that passengers do not need to transfer at stations. The majority of buses pick up patrons on street, similar to conventional bus services. These buses then run directly onto the guideway at selected interchanges.	Yes Initial planning for a high quality transit facility to serve the developing northeastern suburbs of Adelaide, a city of 1.1 million people, led to a decision in 1979 to construct a light rail transit (LRT) line. However, a change of government resulted in a politically-led decision to instead construct a guided busway using the O-Bahn technology.	Yes Typical Cross Section Available. Total width 20.3 feet (6.2 m)  Adelaide O-Bahn – Typical Section
Existing BRT with future LRT conversion	South East Busway	Brisbane (Australia)	The South East Transit Project was a $599 million major public transport infrastructure project featuring Brisbane's first dedicated line-haul busway system the South East Busway, complete with 10 high quality rapid transit stations (3 below grade) integrated with adjacent urban development and significant pedestrian and cycle networks. The 16km Busway has a combined total of 1.6km of tunnels and 2.2km of bridges The South East Busway is located along one side of a six-lane freeway through much of the corridor. The cross section between stations consists of two 3.5-meter [11.5-feet] travel lanes. Bypass lanes are provided at stations to enable express buses to pass buses making stops. At the stations a 0.5-meter [1.6-feet] barrier with a fence separates two 3.5-meter travel lanes. These lanes are flanked by two 3.5-meter [9.8-feet] lanes for stopped buses. The entire busway envelope, including station platforms, occupies a 21-meter [69-feet] right-of-way.	Yes The Busway has been designed for future conversion to light rail in parts: • A side tunnel stub was included in the original design in preparation for the introduction of light rail, this was to permit a future light rail alignment to access the busway along its alignment. • A vibration mat has been installed in one section where the busway alignment passes under a major hospital (Mater Private Hospital). Generally were possible design elements required for LRT were considered these being: • Clearance to structural elements, clearance to pavement • Some service relocations • Concrete pavement design in the station areas, consideration of stray current	Yes Typical Cross section through Busway and Station available  Brisbane South East Busway Main Line Busway - Typical Section  Brisbane South East Busway Station - Typical Section
Existing BRT with future LRT conversion	Inner Northern Busway (INB)	Brisbane (Australia)	The Inner Northern Busway (INB) is a 4.7 kilometer (2.9 mile) segregated busway, with sections both under and above ground, linking the city center to the suburb of Herston. The INB is the second section of an 85 kilometer (53 mile) planned busway network in Brisbane. The INB opened at the beginning of 2004 and with the service enhancements made possible by the facility, transit patronage has already increased by a dramatic 88 percent on key bus routes. On arterials approaching the INB, transit signal priority and exclusive bus lanes	Yes the INB was designed were possible for the future conversion to light rail if and when the need arises.	Yes Typical Cross Section Available as per the South East Transit Project above.

Category	Project Name	Location	Project Description	LRT Conversion Possible (Y or N) Allowances made in Design	Cross Section Available
			help speed the flow of buses into the INB. Travel time was reduced by limiting the number of busway stations, which are about 2 kilometers (1.2 miles) apart.		
Existing BRT with future LRT conversion	SilverLine BRT	Boston, Massachusetts (USA)	The 4.1-mile [6.6-km] Silver Line BRT connecting Dudley Square, South Station, and the South Boston Seaport will add a fifth rapid transit line to downtown Boston. The transit way will include three sections: • Section A, a 1.1-mile [2-km] bus tunnel between South Station and the Waterfront, is scheduled to open by 2004 • Section B, a 2.2-mile [3.5-km] section of curbed bus lanes with improved stations along Washington Street between Dudley Square and downtown opened in 2002; and • Section C, a tunnel link between South Station and Washington Street is scheduled to open by 2010. The redesign of Washington Street involves providing two travel lanes, a left-turn lane, curb bus lanes, and curb parking lanes between stations. The bus tunnels are being designed to be similar to an LRT Line. There is a single travel lane in each direction with right-side stations. Subway stations will be 220 feet long, thereby enabling three articulated buses to load and unload at the same time. A mezzanine concourse over the tunnel at the stations provides access to both directions of travel and contains areas for prepayment of fares.	The early designs for the Boston SilverLine (originally South Boston Piers Busway) were designed for conversion to LRT	Yes Typical Cross Section Available however lane dimensions to be confirmed  Boston Silverline – Washington Street Typical Section  Boston Silverline – Bus Tunnel Typical Section  Boston SilverLine – Conceptual Bus Station Typical Section
Proposed BRT only	Euclid Avenue BRT	Cleveland, Ohio (USA)	The planned 6.6-mile [10.6-km] 30-station Euclid Avenue BRT will include a total package of improvements that are designed to achieve more efficient transit service along Euclid Avenue and improve access between Downtown Cleveland and University Circle. The project will extend from Downtown Cleveland to the Stokes (Windermere) Rapid Transit Station – a distance of about 7 miles [11.3 km]. The western 4.5 miles [7.3 km] will have median bus lanes, and buses will operate in mixed traffic for the eastern 2.5 miles [4 km]. The project consists of: 1. *Bus Rapid Transit (BRT) Service Along Euclid Avenue* between Downtown Cleveland and the Stokes Red Line Station in Windermere. Hybrid diesel electric buses would operate in exclusive median bus lanes between Public Square and 107th Street and in mixed-flow curb lanes east of 107th Street. There would be approximately 30 bus stops along the 6.6-mile [10.6-km] route, half of the current number. 2. *Streetscape Improvements* along Euclid Avenue, including a tree-lined street,	The Euclid Corridor was originally planned to leave open the possibility of rail conversion. However, current design and operation plans will make the conversion very difficult to implement.	Yes Typical Cross section for Left Side Boarding, Right Side Median Boarding and Right Side Curbside Boarding available (Not yet shown)

Category	Project Name	Location	Project Description	LRT Conversion Possible (Y or N) Allowances made in Design	Cross Section Available
			new sidewalks, and a landscaped central median (West of 107th Street). 3. *A Downtown Transit Zone* bounded by West 3rd Street, St. Clair Avenue, East 17th Street and Superior Avenue. This zone includes exclusive bus lanes on Superior Avenue and St. Clair Avenue. 4. *Two New Downtown Transit Centers*, one on West 3rd Street and one on East 23rd Street. 5. *Improved Access to Three Red Line Transit Stations* – East 55th Street, East 105th Street, and University-Cedar. The BRT plan provides for two travel lanes plus median bus lanes between Public Square and East 107th Street and four travel lanes (including shared curb lanes to the east). Throughout, there would be additional left-turn lanes at key intersections. Three basic treatments are planned: 1. Between Public Square and East 18th Street, median bus-only lanes will be flanked by a central landscaped median and separated from a single traffic lane each way by a 1-foot rumble strip. Buses would receive and discharge passengers at median stations. 2. Between East 17th Street and East 107th Street, median bus-only lanes will be flanked by a central landscaped median and be separated from a single traffic lane each way by a 1- foot rumble strip. Special right-side far side stations will be provided at bus stops. 3. Between East 107th Street and the East City Limits, buses will operate in the curb lanes in mixed traffic flow. 4. The "rumble strips" that delineate the median bus lanes will permit buses and cars to change lanes when the lane they are using is blocked. However, the absence of a physical barrier (e.g., a low mountable curb) will require steady enforcement of the bus lanes. The bus lanes would also be available for use by emergency vehicles. Each of the 30 bus stops will be designed to accommodate two buses simultaneously. The stations will have shelters and amenities and may include fare vending machines to speed passenger boarding. Stations will be spaced at about 150 foot intervals as compared with the existing 500-foot spacing.		
Existing BRT with future LRT conversion	Curitiba BRT	Curitiba (Brazil)	Curitiba's median busways have been progressively expanded over the last 30 years. The first 20 km [12.4 miles] were planned in 1972, built in 1973, and placed in service in 1974. In 2001, there were 40 km [37 miles] of busway along the five structural axes. A trunk and feeder bus system operates in which buses are routed through a series of terminals where passengers transfer between busway vehicles, feeder routes, and inter-district links with no further payment of fares. Buses, which are operated by private companies under municipal supervision, use a common color-coding system. The Curitiba busways are located along "structural axes" that comprise three roads, the central one of which is a busway and service-access road. Busways are continuous along five corridors or structural axes with a total length of 58 km. Busway characteristics are the following: • Used exclusively by trunk line buses. • Separated from other service-access traffic by continuous physical islands or by island bus stop platforms. • Busway crossings with other roads are generally at grade and signal controlled (it is believed bus traffic signal actuation exists). • Located in the center of the bus and service-access road, and thus, the busway-road, unlike many attempted adaptations of the "Curitiba principle" in other cities, is not a major traffic-carrying route. Passenger access to/from stops does not involve crossing through dense, possibly fast moving traffic. • The curb-to-curb envelope contains eight lanes; it is about 26 meters [85 feet] wide. • Tube stations preempt the parking lanes adjacent to the busway. Due to ongoing increases in the city's population, Curitiba's bus system is expected to reach maximum capacity in the near future. As a way of offsetting	Yes The city has announced that it will study replacement of buses with "electric tramcars" – that is, surface light rail transit – on the two busiest busways. There is currently plan to convert a Federal highway into an avenue with a partly elevated metro. The first 13km section with 9 stations will be built within 5 years and is expected to serve 83,000 persons per day. The completed project, in many ways not unlike the rubber tyred system of the Paris metro but without rails (similar to a model used in Japan), will eventually be extended to a total of 27km.	Yes Typical Cross Sections available  Curitiba Busway Mid Block – Typical Section  Curitiba Busway Bus Platforms – Typical Section

Category	Project Name	Location	Project Description	LRT Conversion Possible (Y or N) Allowances made in Design	Cross Section Available
			this problem, there are plans to divert a highway running north-south through Curitiba to the suburbs, and convert the original highway route into a new monorail-based transport system.		
Planning stage BRT only	East West Pilot BRT	Eugene - Springfield Oregon (USA)	The pilot corridor will be part of a long-range goal for implementing a metropolitan-wide BRT network. It will be composed of an east-west corridor extending 10 miles [16 km] from the Thurston area in east Springfield to west Eugene. Initially, the first phase will be a 4-mile [6.5-km] segment with nine stations connecting downtown Eugene with downtown Springfield, the two major transit hubs. The bus rapid transit system will operate with a variety of corridor treatments. Most of the route will operate on an exclusive transitway. However, it is recognized that not all locations in the identified corridor will have the right-of-way for such operations, and will require mixed traffic operations (i.e., a bridge). It is expected that operations will include electronically guided transit as well as more traditional transit lanes. In areas with bus lanes, a different pavement treatment will help differentiate the lanes from general purpose lanes. Another special situation involves a single lane being used to accommodate BRT vehicles traveling in two directions (time separated). Block signaling will be used with priority given to the peak-direction bus movements in the single-lane busways. Phase One is to be constructed primarily within the right-of-way of existing streets. The BRT line will use a combination of guideways, transit lanes, and travel in mixed traffic. A combination of both single-lane and double-lane guideways and transit lanes will be used. The BRT line will deviate from the main arterial street in one section of the corridor. The guidance will be magnetic, differential global positioning systems (dgps), and dead reckoning. This guided BRT design allows for reduced lane-width requirements. Steering is automated through the electronic guidance, which only requires pavement under the wheel tracks. This provides an opportunity for the inclusion of additional green space between the tracks. The guided bus technique allows for "precision docking" at the stations. BRT lanes are designed at 10.5' wide. This is equal to the width of the bus measured between the outside edges of the mirrors.	No	Yes Typical Cross Section of the Guided Busway available BRT lanes are designed at 10.5' wide, breakdown of width to be determined  East / West Pilot BRT – Eugene / Springfield
Planning / Design Phase	The New Britain–Hartford Busway	Hartford, Connecticut (USA)	The 9.6-mile (15.4-km) exclusive New Britain–Hartford Busway will provide up to 12 stations. The busway, which will be located along the Amtrak/Conrail Railroad and an abandoned rail right-of-way, will parallel I-84 and provide an alternative for regional trips. The 9.6-mile busway would have 18 grade separations and 8 signal-protected grade crossings. It would connect with freeways and city streets in New Britain and with city streets in downtown Hartford. Intermediate bus access is planned at about seven locations. The busway would be illuminated at stations. The roadway surface would pave over portions of the abandoned and active railroad rights-of-way. This dedicated two-lane roadway (one lane in each direction) would be exclusively reserved for buses. However, at stations, additional lanes would be provided to allow non-stop buses to bypass stopped buses that are receiving or discharging passengers. The roadway would be protected on each side by "Jersey" barriers and fences to keep unauthorized vehicles and people off the roadway. This protection would result in a 30-foot-wide envelope.	Yes LRT was considered in the early planning phases of the design.	Yes Typical Sections available  New Britian / Hartford Busway - Typical Section

Category	Project Name	Location	Project Description	LRT Conversion Possible (Y or N) Allowances made in Design	Cross Section Available
					 New Britian / Hartford Busway Opposite Station - Typical Section
Planning Phase LRT Project that was original BRT	Houston Southeast-Universities-Hobby corridor AA/DEIS	Houston, Texas (USA)	The Houston Southeast-Universities-Hobby corridor is part of METRO MOBILITY 2025, the long-range system plan for continued development of the Houston region's transit system. This study will identify needed transit improvements in southeastern Houston. All three corridors during the design phase of the project were to consider two technology alternatives, one being light rail, and the other BRT designed for possible later conversion to LRT. The three corridors have mostly in-street exclusive-lane alignments, so it is probably would be most practical to convert from bus to rail by having buses leave the guideway and use adjacent traffic lanes as limited-length sections of the guideway underwent track installation. The BRT criteria called for stations just like LRT stations, with 14-inch-high platforms, and with bus guidance at least in the stations. There was no specific planning for the conversion process, and LRT was subsequently chosen as the LPA. Originally the project was required to design all BRT alternatives for the 13 corridor AA's to be convertible to LRT during the formulation of the new long range plan, Metro Solutions. However, LRT was adopted as the basic technology by the Metro Board. During the design phase when BRT was being considered the one intention was to use buses with doors on both sides to allow use of either center platform or side platform stations. This being the case, another conversion strategy would be temporary "single-track" operation at stations, while rails were being installed in the other trackway. The same approach could of course be used on line sections between stations	Yes Underground in-street utilities, which usually are relocated outside the trackway for LRT, but less likely to be moved for BRT. In Houston the BRT cost estimates assumed the same extent of utility relocation for BRT as for LRT.	Yes Typical Cross Sections Available  Houston/Southeast Universities Corridor Bus Only - Typical Section  Houston/Southeast Universities Corridor Bus and General Traffic - Typical Section  Houston/Southeast Universities Corridor Bus Station - Typical Section

Category	Project Name	Location	Project Description	LRT Conversion Possible (Y or N) Allowances made in Design	Cross Section Available
Proposed BRT with future LRT conversion	Jacksonville North-Southeast Busway	Jacksonville, Florida (USA)	The North/Southeast Corridor is 32 miles in length and connects the north and southeast sections of the First Coast community. The proposed BRT guideway will be a two-lane bus-only road with barriers	Yes Horizontal and vertical alignment considered LRT requirements	Not yet available
Existing BRT, initial plans for conversion to LRT but now no	El Monte Busway	Los Angeles, California (USA)	The El Monte Busway on the San Bernardino (I-10) Freeway is located in eastern Los Angeles County, stretching from El Monte to downtown Los Angeles. The Busway was opened in 1973 and 1974, making it one of the earliest HOV facilities in the country. A one-mile extension into the downtown area was opened in 1989, providing a link to the Los Angeles Union Passenger Terminal. The two-way HOV facility includes two design treatments. From El Monte to I-710, the Busway is located in the center of the I-10 Freeway, separated from the general-purpose lanes by a 10.5-foot painted striped buffer. From I-710 to downtown Los Angeles, the Busway is located adjacent to, but separated from, the I-10 Freeway. One-way lanes built on the median strip or alongside the freeway are separated from general traffic lanes by concrete barriers or a buffer lane with traffic posts. The 6.6- mile [11-km] section between El Monte and the Long Beach Freeway is located in the freeway median. A 20-foot [6-meter] railroad opening is maintained in the median and flanked by a median wall, a 17-foot [5-meter] busway, a 3-foot [1-meter] flexible post every 50 feet [15 meters], a 10-foot [3 m] common shoulder, and then four freeway lanes. A 3.8-mile [6-km] section adjacent to the freeway between Mission Road and the Long Beach Freeway consists of a 54-foot [16.5-meter] two-way busway with 12-foot lanes [3.6-meters], an 8-foot [2.5-meter] right shoulder, and a 4-foot [1.2-meter] left shoulder in each direction separated by a barrier. Contra-flow operation exists west of the California State University to the Santa Ana/San Bernardino Freeway interchange. The transposed operations facilitate access to and from the busway. A circular island platform at the El Monte Station provides for easy transfer between express and feeder bus lines. There is a large park-and-ride lot (over 100 spaces) at this location as well as an island station on one side.	Yes	Yes Typical Cross Sections Available  Los Angles El Monte Busway – Typical Section 1  Los Angles El Monte Busway – Typical Section 2
Existing guided BRT with no plans for conversion to LRT	Metropolitan Area Express (MAX)	Las Vegas, Nevada (USA)	The optical guided BRT route runs along Las Vegas Boulevard North from the Downtown Transportation Center to Nellis Air Force Base in North Las Vegas. A dedicated bus lane runs most of the length of the project. Only buses, MAX and right-turning vehicles will be allowed in this lane. Traffic signal improvements will be implemented giving buses and MAX signal priority at intersections. Along the route, existing bus stops will receive upgrades and new MAX platforms will be constructed. The optical guidance systems help to reduce the need for building specific type of guided running ways and help with precision docking at stations and the like.	No	No Typical Sections Available as Bus Lane only
Existing BRT in rail corridor	South Miami Dade Busway	Miami, Florida (USA)	The South Miami-Dade Busway is an 8.2-mile (13 kilometer), at-grade roadway for exclusive use by buses and emergency/security vehicles. The Busway, which was built mainly in an abandoned railroad right-of-way, connects the Dadeland South Metrorail station with Cutler Ridge. Except for the approach to the Dadeland South Metrorail station, the bus lanes are located in the center of a 100-foot (30-meter) right-of-way. Each lane is 12	Information not available	Yes Typical Section Available shoulder widths to be confirmed (varies)

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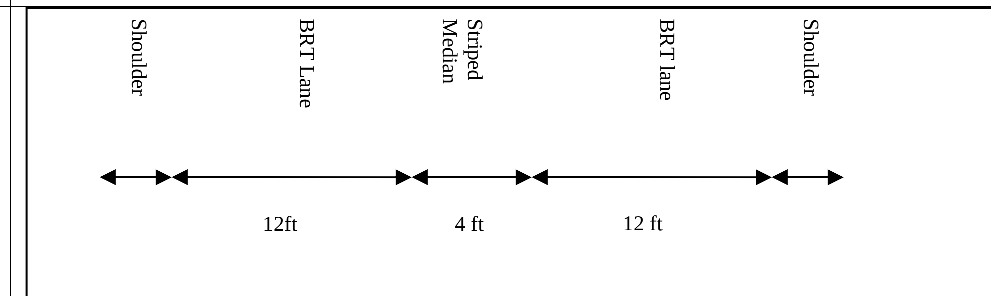
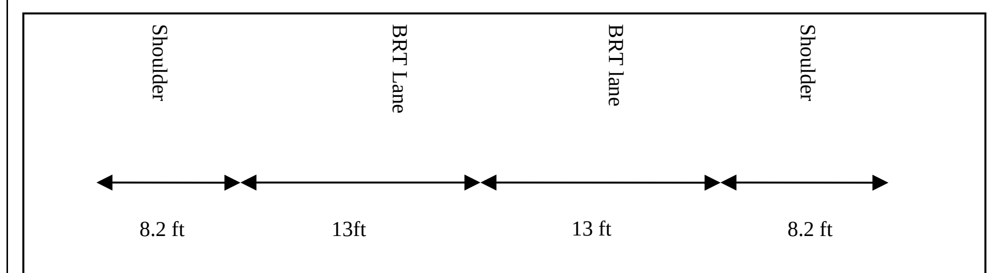
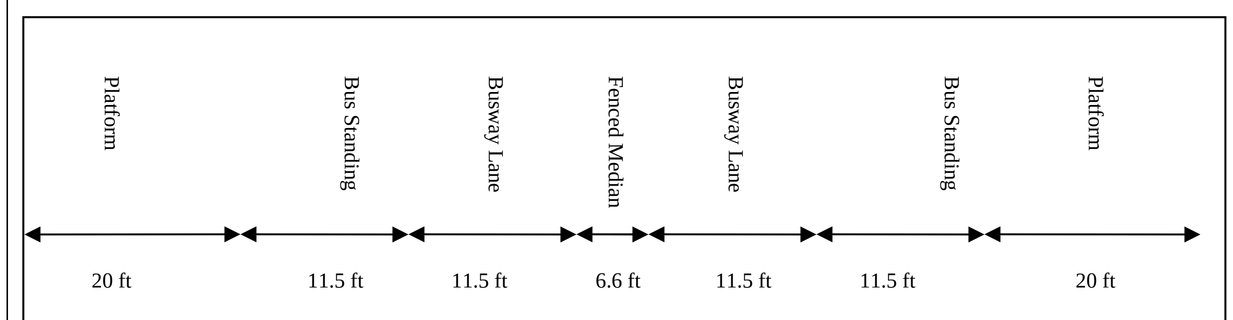
			feet (4.0 meters) wide. Lanes are divided by a 4-foot (1.2-meter) striped median. The bicycle path located to the west of the paved bus lane is about 8 feet (2.4 meters) wide. At the approach to Dadeland South, the right-of-way narrows; there is no swale or median, and the bicycle lane is separated from the bus lanes by a curb. There are 15 stations in each direction along the Busway. The Busway width varies from 28 feet to 52 feet at stations to enable express buses to bypass stopped vehicles. Stations are long enough to allow several buses to stop at the same time. Stations are located at major intersections and are spaced about 1/2 mile (1 kilometer) apart. At most intersections, the stations are located on the far side of the intersection.		 South Miami Dade Busway – Typical Section
Existing BRT with future LRT conversion	Ottawa, Transitway	Ottawa, Ontario (Canada)	Ottawa's complete "BRT" system consists of 16.0 miles of dedicated "transitways" (busways), with 26 stations; 1.2 route-miles of CBD reserved lanes (on two parallel streets); 2.0 miles of mixed-traffic running (Ottawa River Parkway); and 6.6 miles of freeway shoulder lanes – totaling 25.8 route-miles. The Transitway is a two-lane, grade-separated, bus-only roadway. The basic right-of-way has two 4-m (13-feet) travel lanes and 2.5-m [8-feet] shoulders on each side for a total width of 13 m [43 feet]. The shoulders provide a place to store snow and accommodate disabled buses. At stations, the right-of-way is widened to include (1) a fenced median that inhibits grade crossings by passengers and (2) another lane in each direction to allow buses to overtake each other. Normal operating speeds on the Transitway are 80 kph [50 mph], restricted to 50 kph [31 mph] or less through stations. During the planning stage of the design it was the view that rail-based systems were likely to be affordable for a city the size of Ottawa. It was also concluded that the bus-based transitway, basically the system that exists today, would be adequate to support a population level of about 625,000 (estimated to occur by 1991), which, more or less, is the current population of OC Transpo's service area. It was estimated that a bus-based system could be built for half the capital costs of light rail and would be about 20 percent cheaper to operate. Another reason for the initial use of Busway rather then LRT was to limit the number of modal changes. It was anticipated that in the future some form of grade-separated transit service within the central area would be required and that possibly the Transitway itself might have to be converted to some form of rail transit technology. OC Transpo is now in the process of completing its first experiment with LRT, but as a *complement* to, rather than as a *substitute* for an upgrade to existing Transitway service. The new plan would build dual-line light rail across the city, and will include expanding electrified light rail and bus Transitway services as far as Barrhaven and Cumberland, over a period of 20 years, and at a cost of $150 million per year. The plan is to make the entire line dual track and run it right through the downtown.	Yes Design provisions include vertical clearances, other elements of geometric design, and structural loadings to accommodate light rail vehicles	Yes Typical Cross Section dimensions available  Ottawa Transitway Main Line – Typical Section  Ottawa Transitway Busway Station – Typical Section
Existing BRT with LRT future conversion	Pittsburgh East Busway (Martin Luther King Jr., Busway), South Busway, West Busway	Pittsburgh, Pennsylvania (USA)	East Busway: The 6.8-mile [11-km] East Busway was opened in 1983. Some 36 routes on the six station facility carry 28,000 riders each weekday. The busway, shares its right-of-way with a relocated rail right-of-way. A 2.3-mile [4-km] easterly extension of the East Busway, under construction, is scheduled to open during 2003. The busway will have four stations, about 900 park and ride spaces, and a linear park. Ridership is estimated at 13,600 weekday passengers. The East Busway design included provision for future conversion to LRV, either joint Bus-Rail use or exclusive LRV use. South Busway: The 4.3-mile [7-km] South Busway was placed in service in 1977. Some 16 routes on the eight-station facility carry 13,000 weekday riders. The South Busway has two sections of joint Bus - LRV operation including a retrofitted 100 year old tunnel. The South Busway also included spacing signals common to both Bus and LRV.	Yes Clearances designed to accommodate LRT Some structural allowances for LRT • notches in the retaining walls for future catenary columns • additional weights / loadings of the track structure and revenue vehicles in the design of the roadway pavement slab and bridge structures. • additional horizontal and vertical clearances for the added track structure and	Yes Typical cross section available, bus standing lane dimensions to be confirmed

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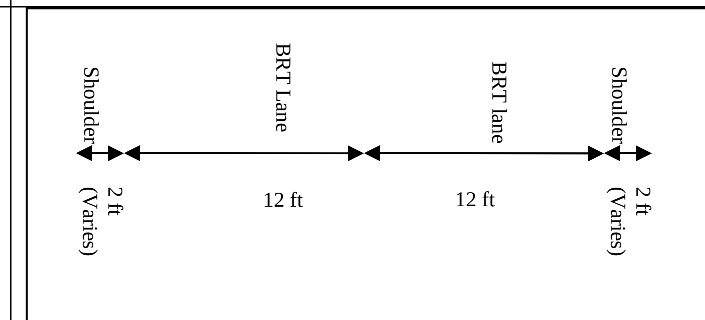
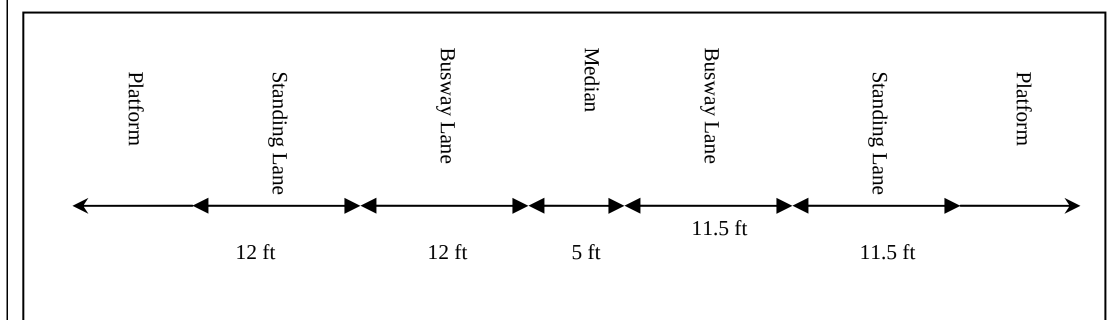
			West Busway: The 5.6-mile [9-km] West Busway opened in September 2000. Some 14 routes on the six-station facility carry about 7,000 riders per day. The busway, follows an abandoned rail line and uses a rehabilitated rail tunnel. General: The busways are essentially two-lane, bus-only controlled access roadways. The geometric design of the busways is adequate for possible future conversion to light-rail transit. Design speeds are 60 mph on the East and West Busways and 50 mph on the South Busway. Bus operating speeds are 55 mph on the West Busway, 50 mph on the East Busway and 40 mph on the South Busway. Speeds on access ramps are limited to 15 to 25 mph. Travel lanes are 12 feet wide except for a 0.1-mile segment west of the East Liberty station and the Mt. Washington Tunnel where they are 11 feet wide. Shoulders are provided wherever possible, ranging from 2 to 10 feet. On the East Busway, for example, shoulders are generally 8 feet for the outbound lane and 2 feet for the inbound lane. At stations, the busways are widened to four lanes; a fence or median separates opposing directions of flow and channelizes or precludes pedestrian crossings. Each bus access point is designed as a simple intersection with appropriate acceleration and deceleration lanes where practical. Where busways join public streets, signs, pavement markings, and traffic signals provide control movements. Several street intersections were widened to improve bus access. The Busway Stations are side platform, "pull-off" style allowing thru lanes for express bus and/or skip stop operation. It was not decided how the LRV station operation would be accommodated; however, the pull-off could accommodate the rail alignment and/or turnouts as well.	LRV dynamic envelope, including OCS and side poles / span wires / mounting brackets / etc. • alignment - horizontal and vertical curves, grades , etc. • clearances are set to allow for light rail vehicles and the erection of centenary wires • Underground structures are designed to accept light rail loadings • Rails and other LRT systems components are not installed during the initial busway construction	 Pittsburgh Mainline – Typical Section  Pittsburgh Bus Stations – Typical Section
Planning LRT only	Sacramento Downtown / Natomas / Airport (DNA) Corridor Alternatives Analysis (AA) extension	Sacramento, California (USA)	Currently in the Planning stage, eight of the twelve alternatives would construct a new LRT or BRT transit guideway from downtown Sacramento, through South and North Natomas, to the Sacramento International Airport; and two minimum operable segments would provide a new transit guideway between downtown Sacramento and the Natomas Town Center. The remaining two alternatives, the No-Build Alternative and Baseline/TSM Alternative, have been carried forward as legitimate alternatives, and for comparison purposes. The locally preferred alternative is Light Rail Transit along Truxel Road. The Corridor area consists of approximately 34 square miles The Sacramento DNA extension was examined in terms of BRT as well as LRT alternatives. For BRT the cross section was only 20 feet 4 in wide while LRT in street running was 24 feet and LRT in exclusive ROW was 34 feet.	No	No not yet available
Existing LRT Only	North South CBD to University LRT	Salt Lake City, Utah (USA)	The project extends 2.5 miles from the North/South LRT line in downtown Salt Lake City to Rice-Eccles Stadium on the University of Utah campus. The proposed University LRT line includes four stations and five light rail vehicles (LRV).	-	-
Existing BRT with future LRT conversion	Seattle Bus Tunnels	Seattle, Washington (USA)	The 2.1-mile [1.3-kilometer] downtown bus tunnel	Yes Tracks were installed Adequate Clearances for LRT vehicles were provided	
Existing BRT with future LRT conversion	Liverpool – Parramatta Transitway Project in Sydney	Sydney (Australia)	The Liverpool – Parramatta Transitway is a 30 kilometer (18.6 mile) system linking Sydney's second central business district to the high growth areas of southwestern Sydney and was opened in early 2003. Some 20 kilometers [12.4 miles] of new bus-only roads will be built, and 10 kilometers [6.2 miles] of bus-only lanes will be provided on existing roads. There will be 35 stations, mostly along the curb. Two third of the line is on an exclusive facility, while the other third operates on existing roads. The system includes a wide range of BRT strategies, including transit signal priority at signalized intersections and real-time passenger information at all 30 transit stations. Bus priority has been provided for the most part by traffic signal pre-emption rather than grade separation. This project is part of a much larger planned system the ultimate network will consist of about 90 kilometers (56 miles) of transitway or BRT lanes.	Yes The design of the Transitway allowed for the conversion to light rail if demand warrants: Structures and grades matched light rail standards	Yes Typical Section Available however confirmation of lane dimensions required

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					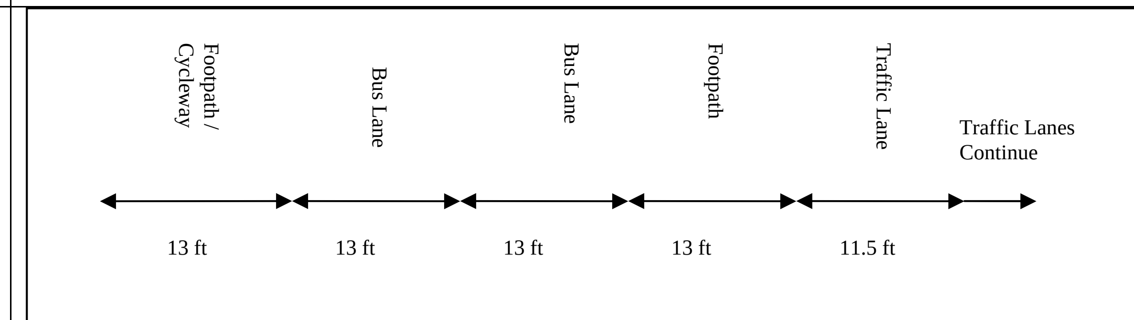
Existing BRT only	TransLink #98 and #99, B-Lines	Vancouver, British Columbia (Canada)	Vancouver has two "rapid" bus lines that represent prototypes for future expansion of bus rapid transit (BRT) service to other corridors. The 27-km (17-mile), 14-stop, #99 B-Line (Broadway-Lougheed) Rapid Bus, which opened in September 1996 and the 15.8-kilometer (10-mile) #98 B-Line (Richmond-Vancouver) was placed in service in August 2001. The #98 B-Line includes suitably sized, well-lit, distinctive shelters; provisions for future on-street ticketing; real-time electronic bus information displays at stations; low-floor vehicles for easy boarding; on-board visual and audio stop announcements; and distinctive vehicle interior and exterior design. BRT in Vancouver uses low-cost treatments in congested areas such as short queue jumper lanes and bus pre-emption signals to allow buses to bypass queues of traffic at bridgeheads and major intersections. Exclusive curbside and median busway lanes are also provided where traffic volumes warrant them.		No Buses use existing road infrastructure not separate bus only right of sway.

Categories:
Originally LRT but converted to BRT
BRT with future LRT conversions
BRT only (without LRT Provisions)