CHAPTER **2**

SYNTHESIS OF FINDINGS

This chapter synthesizes the experience of 26 case studies of BRT located in the United States, Canada, Australia, Europe, and South America. It starts by defining the concepts and attributes of BRT and traces BRT's evolution over the years. It then identifies where BRT systems operate and how they were successfully implemented. The case studies are then compared in terms of physical features (running ways, stations, vehicles, and ITSs); performance (ridership and speeds); and benefits achieved.

2.A BRT—CONCEPTS AND EVOLUTION

There is a broad range of perspectives as to what constitutes BRT. At one end of the spectrum, BRT has been defined as a corridor in which buses operate on a dedicated right-of-way such as a busway or a bus lane reserved for buses on a major arterial road or freeway. Although this definition describes many existing BRT systems, it does not capture the other features that have made rail rapid-transit modes so attractive around the world.

BRT has also been defined as a bus-based, rapid-transit service with a completely dedicated right-of-way and on-line stops or stations, much like LRT. This is consistent with the FTA definition of BRT as "a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses" (*1*).

For the purpose of this project, BRT has been defined more comprehensively as a flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways, and ITS elements into a fully integrated system with a strong image and 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 to streets and highways where transit is mixed with traffic).

In brief, BRT is a fully integrated system of facilities, services, and amenities that are designed to improve the speed, reliability, and identity of bus transit. In many respects, it is rubber-tired LRT, but with greater operating flexibility and potentially lower capital and operating costs. Often, a relatively small investment in dedicated guideways can provide regional rapid transit. This definition has the following implications:

- Where BRT vehicles (buses) operate totally on exclusive or protected rights-of-way (surface, elevated, and/or tunnel) with on-line stops, the level of service provided is similar to that of heavy rail rapid transit (metros).
- Where buses operate in combinations of exclusive rights-of-way, median reservations, bus lanes, and street running with on-line stops, the level of service provided is similar to that of LRT.
- Where BRT operates almost entirely on exclusive bus or HOV lanes on highways (freeways and expressways) to and from transit centers with significant parking and where it offers frequent peak service focused on a traditional CBD, it provides a level of service very similar to that of commuter rail.
- Where buses operate mainly on city streets with little or no special signal priority or dedicated lanes, the level of service provided is similar to that of an upgraded limited-stop bus or tram system.

Figure 1 describes the seven major components of BRT—running ways, stations, vehicles, service, route structure, fare collection, and ITS. Collectively, these components form a complete rapid-transit system that can improve customer convenience and system performance (*2*).

2.A.1 Why BRT?

Transportation and community-planning officials all over the world are examining improved public transportation solutions to mobility issues. This renewed interest in transit reflects concerns ranging from environmental consciousness to the desire for alternatives to clogged highways and urban sprawl. These concerns have led to a re-examination of existing transit technologies and the embrace of new, creative ways of providing transit service and performance. BRT can be an extremely cost-effective way of providing high-quality, high-performance transit.

Advancements in technology such as clean air vehicles, low-floor vehicles, and electronic and mechanical guidance

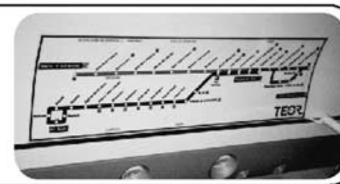
Running Ways	BRT vehicles operate primarily in fast and easily identifiable exclusive transitways or dedicated bus lanes. Vehicles may also operate in general traffic.	
Stations	BRT stations, ranging from enhanced shelters to large transit centers, are attractive and easily accessible. They are also conveniently located and integrated into the community they serve.	
Vehicles	BRT uses rubber-tired vehicles that are easy to board and comfortable to ride. Quiet, high-capacity vehicles carry many people and use clean fuels to protect the environment.	
Services	BRT's high-frequency, all-day service means less waiting and no need to consult schedules. The integration of local and express service can reduce long-distance travel times.	
Route Structure	BRT uses simple, often color-coded routes. They can be laid out to provide direct, no-transfer rides to multiple destinations.	
Fare Collection	Simple BRT fare collection systems make it fast and easy to pay, often before you even get on the bus. They allow multiple door boarding, reducing time in stations.	
Intelligent Transportation Systems	BRT uses advanced digital technologies that improve customer convenience, speed, reliability, and operations safety.	

Figure 1. Components of bus rapid transit.

systems have made BRT a more attractive transit alternative to both transit users and transportation-planning officials. Several reasons were cited repeatedly in the case studies for considering BRT as a potential high-performance transit investment. These reasons are the following:

- Continued growth of urban areas, including many CBDs and suburban activity centers, has created a need for improved transport capacity and access. Given the costs and community impacts associated with major road construction, improved and expanded public transit emerges as an important way to provide the needed transportation capacity. However, existing conventional bus systems are often unattractive, difficult to use, slow, unreliable, and infrequent in service. In addition, their vehicles are often not well matched to their markets, and they have little if any passenger information and amenities at stops. Rail transit can be difficult, time-consuming, and expensive to implement; costly to operate; and poorly suited to many suburban travel markets.
- BRT can often be implemented quickly and incrementally without precluding future rail investment if and when it is warranted.
- For a given distance of dedicated running way, BRT is generally less costly to build and equip than rail transit. Moreover, there are relatively low facility costs where BRT vehicles operate on existing bus-only or HOV lanes or in mixed traffic.
- BRT can be cost-effective in serving a broad variety of urban and suburban environments. BRT vehicles, whether driver-steered or guided mechanically or electronically, can operate on streets, freeway medians, railroad rights-of-way, arterial structures, and underground. BRT can easily and inexpensively provide a broad array of express, limited-stop, and local all-stop services on a single facility, unlike most rail systems.
- BRT can provide quality performance with sufficient transport capacity for corridor applications in most U.S. and Canadian cities. The Ottawa Transitway system's CBD link, for example, carries more people in the peak-hour peak direction than most LRT segments in North America. Many BRT lines in South American cities carry peak-hour passenger flows that equal or exceed those on many U.S. and Canadian fully grade-separated rail rapid-transit lines.
- At the ridership levels typically found in most urban corridors, BRT can have relatively low operations and maintenance costs. This is primarily because the relatively low fixed maintenance costs can offset variable driver costs.
- BRT is well suited to cost-effectively extend the reach of existing rail transit lines by providing feeder services to areas where densities are currently too low to support rail transit. It can also serve as the first stage for an eventual rail transit line.
- Like other forms of rapid transit, BRT can be integrated into urban and suburban environments in ways that foster economic development and transit- and pedestrian-friendly design. Examples of regions that have integrated BRT successfully include Adelaide, Boston, Ottawa, and Brisbane.
- Advancements in the practical application of several technologies also make BRT feasible. These include
  –"Clean" vehicles (CNG, diesel-electric hybrid, and dual power buses);
  –Low-floor vehicles that allow quick, level boarding; and
  –Mechanical, optical, and electronic guidance systems.

2.A.2 Evolution of BRT

The idea of using rubber-tired vehicles (buses) to provide rapid transit is not new. Plans and studies have been prepared since the 1930s, with a growing emphasis on rubber-tired vehicles in the last few years.

Major Proposals

BRT proposals were developed for Chicago in 1937, Washington D.C. in 1956–1959, St. Louis in 1959, and Milwaukee in 1970. These plans are discussed briefly below.

1937 Chicago Plan. BRT was first suggested in Chicago (*3*). A 1937 plan called for converting three westside rail rapid-transit lines to express bus operation on super highways with on-street distribution in central areas and downtown.

1956–1959 Washington D.C. Plan. Design studies for BRT within freeway medians were developed as part of the 1956–1959 "Mass Transportation Survey for the National Capital Region" (*4*). It was recommended that "in planning of future radial freeways a cross section . . . be provided to afford maximum flexibility and reserve capacity for vehicles as well as for the mass movement of people." This plan called for a three- or four-lane roadway for traffic in each direction. These roadways would be separated by a 64-foot mall with 51 feet from center to center of the columns supporting cross-street bridges. In the first stage, this wide mall would be landscaped and held available for future developments; public transportation would consist of express buses operating in the general traffic lanes.

Buses would make stops at appropriate intervals on the parallel service roads without special station facilities or at simple stations within the end span of the cross-street bridges. Express bus service eventually would be converted to BRT and rail within the median.

1959 St. Louis Plan. The 1959 transportation plan included an 86-mile BRT system, of which 42 miles were to be special grade-separated bus roadways (*5*). The focus of this proposal was an elevated loop road circling downtown St. Louis, measuring six blocks north and south and five blocks east and west. The loop contained a 60-foot-wide operating deck that included a sidewalk or passenger-loading platform located on the inner side of the deck to mesh with one-way clockwise operation of buses. It provided a three-lane bus roadway approximately 37 feet wide. The BRT system cost totaled $175 million (exclusive of freeways).

1970 Milwaukee Plan. Milwaukee's proposed 1970 transitway plan included 107 miles of express bus routes over the freeway system and an 8-mile, east-west transitway (*6*). The plan called for 39 stations (excluding downtown) and 33,000 parking spaces.

In 1990, during the p.m. peak hour, 600 buses would enter the Milwaukee CBD as compared with 135 in 1973. Costs for the BRT system were estimated at $151 million (1970), $40 million of which was for the transitway. The plan was integrated with existing and proposed freeways.

Research and Planning Studies

Several research studies described where BRT would work and how it might be configured. A 1966 study done for the American Automobile Manufacturers Association, *Transportation and Parking for Tomorrow's Cities* (*7*), set forth broad transportation-planning guidelines. It indicated that "bus rapid transit is especially suitable in cities where downtown must attract its visitors from a wide, diffused area." It stated that

> BRT could involve lower capital costs, provide greater coverage, better serve low and medium-density areas, and more readily adapt to changing land-use and population patterns than rail-based systems.
>
> BRT also has applicability in larger cities of much higher density because of its operational flexibility, and with proper downtown terminal design, bus rapid transit systems could provide adequate capacities to meet corridor demands in nearly all of the Nation's cities which do not have rail systems.

To achieve high average speeds on downtown approaches, buses could operate within reserved lanes or exclusive freeway rights-of-way on key radial routes and could travel outward to the intermediate freeway loop, with provision for subsequent expansion.

Downtown, buses would operate preferably on private rights-of-way and penetrate the heart of the core area (either above or below ground) or, alternatively, they could enter terminals. Successful BRT, however, would require

> careful coordination between highway and transit officials in all stages of major facility planning. In this regard, resolution of several major policy questions will go far toward early implementation of bus rapid transit systems. These are: (1) the extent to which exclusive bus facilities will qualify for federal aid under existing programs; (2) the need for separate designs on approaches to the inner freeway loops and downtown; (3) the minimization or elimination of costly ventilation systems to facilitate underground operation; (4) the development of financing policies for downtown bus tunnels; and (5) the development of bus trains or special bus designs to minimize downtown station requirements and expedite downtown loading. (*7*)

The 1996 study indicated that a small amount of special right-of-way in conjunction with the urban freeway system (where necessary to ensure good peak-hour speeds) could generally provide effective regional rapid transit. It was conservatively estimated that peak-hour downtown cordon volumes of up to 125,000 persons could be accommodated by freeways, BRT, local transit, and arterials under existing capabilities of automobiles and buses. This is ample capacity for the vast majority of U.S. city centers:

> Moreover, as bus technology improves and electronic bus train operation becomes a reality, substantially greater capacities would be achieved. Thus, ultimately, differences between rail and bus transit could become minimal. (*7*)

A 1970 study, *The Potential for Bus Rapid Transit* (*8*), indicated that freeway systems were potentially usable by express buses and, with modification, as exclusive bus lanes or busways. The key factors in evaluating BRT potential were (1) capital costs, (2) operating costs, (3) route configuration, and (4) distribution in the city center and other major activity centers.

In 1973, *NCHRP Report 143: Bus Use of Highways: State of the Art* (*9*) provided a comprehensive review of the state of the art, and, in 1975, *NCHRP Report 155: Bus Use of Highways: Planning and Design Guidelines* (*10*) set forth planning and design guidelines. Using the goal of minimizing total person delay as a guide, the reports suggested ranges in peak-hour bus volumes for bus priority facilities.

A 1972 study, "Bus Rapid Transit Progress in the USA" (*11*), examined and summarized reasons for the implementation of BRT projects in the 1950s and 1960s.

A 1975 study, *Bus Rapid Transit Options for Densely Developed Areas* (*12*), described and evaluated the cost, service, and environmental implications of bus lanes, bus streets, and bus subways. The report showed how various bus priority facilities would be coordinated in the central area and suggested a multidoor articulated bus for BRT operations.

Most of these planning studies focused on the *facility* aspects of BRT, often as an adjunct to urban freeways. Little or no attention was given to the station, service, and image/identity aspects of BRT.

Countervailing Trends

In the middle to late 1970s, the transit planning emphasis shifted away from bus use of streets and highways, BRT, and fully grade-separated metros toward the provision of

HOV lanes and LRT. HOV lanes were perceived as a widely applicable, environmentally positive way of expanding road capacity while reducing single-occupant-vehicle use.

The development of LRT lines gained popularity because of their perceived performance, passenger attractiveness, and image benefits. These aspects were considered to be unattainable by bus transit, but attainable in LRT at costs much lower than those of fully grade-separated metros, such as those in San Francisco; Washington, D.C.; Miami; and Baltimore. LRT tends to be considered more fully in alternative analyses, partially because there is little information available on the potential benefits and costs of BRT.

Recent U.S. Initiatives

FTA has undertaken a BRT initiative in an attempt to encourage local agencies to consider potentially cost-effective BRT alternatives in major investment and alternatives analyses studies. Using Curitiba's BRT system as a model, FTA sponsored a BRT conference in 1998, published major documents highlighting BRT (*13*, *14*), established a BRT Consortium with 17 supporting cities in 1999, and launched a BRT "Demonstration Program" involving 15 cities.

2.B OVERVIEW OF FINDINGS

BRT systems are found today in major cities throughout the world. These systems vary widely in extent, type of treatment, design and operating features, usage, and benefits. Key aspects of the 26 case studies are described in the sections that follow.

2.B.1 Case Study Locations

The locations, urban populations, and key features of the 26 case study cities surveyed are shown in Table A-1 in Appendix A. Most BRT systems are located in large cities, many of which also have rail rapid transit. Nineteen of the systems are found in urban areas of over 700,000, and 16 also have rail transit lines. Nine of the 14 systems in the United States and Canada have a CBD employment that exceeds 85,000.

Twenty-one BRT systems are in revenue service, three are under construction (Boston, Cleveland, and Sydney), and two are under development (Hartford and Eugene).

2.B.2 Reasons for Implementation

The main reasons cited in the case studies for implementing BRT systems were BRT's lower development costs and greater operating flexibility as compared with rail transit. Other reasons were that BRT can be a practical alternative to major highway construction, an integral part of the city's structure, and a catalyst for urban development. Examples of the specific reasons cited for BRT implementation are described below.

United States and Canada

Boston. There has been a need to provide better transit access and more capacity to the growing South Piers redevelopment area and to Logan International Airport. Implementing a BRT system was perceived as providing operational and service benefits rather than merely cost advantages. A limited amount of bus subway construction will provide a one-seat ride to major activity centers such as Logan Airport.

Cleveland. Rail transit on the Euclid Avenue corridor has been proposed for more than a half century, but numerous plans were never realized because of the cost involved and the declining commercial activity in the corridor. Implementing a BRT system was perceived to be more cost-effective and affordable and was seen as a tool for encouraging redevelopment.

Eugene. The proposed BRT system is seen as an environmentally responsive way of alleviating traffic congestion without making costly highway improvements.

Hartford. The busway was found to be a more cost-effective alternative to major freeway reconstruction and more compatible with community-planning goals.

Houston. BRT was able to use Houston's HOV system for running ways. The system, which includes HOV, park-and-ride, and commuter express buses, makes effective use of radial freeway corridors in reducing peak-hour traffic congestion.

Los Angeles. Long delays and cost overruns led to a county referendum prohibiting future subway construction. BRT was seen as a cost-effective alternative to improving bus service in major travel corridors. It was also considered to be a strategy for offsetting a 12% decline in bus speeds in recent years.

Miami. The state of Florida examined cost-effective, affordable public transport uses of an abandoned railroad right-of-way. This led to the decision to build an at-grade busway.

New York City. Morning peak-hour contra-flow bus lanes were viewed as a cost-effective means of increasing the speed of bus travel across the Hudson and East Rivers.

Ottawa. The region's transportation policy gave public transportation projects priority over all forms of road construction or widening. Busway technology was selected because it was cheaper to build and operate. A 1976 study found that a bus-based system could be built for half the capital costs of rail transit and would cost 20% less to operate. It also offered a higher level of service: greater staging flexibility met the capacity requirement of 15,000 passengers per hour in the peak direction and had similar environmental impacts to the rail option (*15*).

Pittsburgh. Busways were politically viable and were easier to implement and more affordable than major highway construction or rail transit. Busways would benefit riders who traveled beyond the limits of the guideways. The Port Authority of Allegheny County was also able to make use of an extensive network of railroad rights-of-way to implement dedicated busways.

Seattle. In the early 1980s, a federal policy of "no new rail starts" required Seattle Metro to explore bus alternatives. A tunnel was selected for its ability to remove buses from downtown streets.

Australia

Adelaide. The Guided Bus system was found to have significantly lower initial costs than a CBD light-rail subway, and it reduced the need for transferring in a low-density corridor. The O-Bahn technology was selected to reduce the cross section of a completely elevated guideway over a riverbed.

Sydney. BRT is being built to provide better transit service to low-density areas with minimum transfer and walk times.

Brisbane. The South East Busway was designed to increase transit level of service in a low-density corridor, to promote transit-oriented development, and to make use of existing HOV lanes on the Southeast Motorway.

Europe

Leeds. The Guided Bus technology provides self-enforcing queue bypasses for buses at congested locations.

Runcorn. The Figure 8 Busway is an integral part of the New Town development.

South America

In South America, there has been an urgent need to improve travel conditions in congested cities with populations that are growing exponentially. There generally have been neither time nor resources to build rail transit. Busways in the center of wide arterial streets emerged as a means of increasing bus performance and capacity.

Bogotá. The TransMilenio four-lane median busway was built after a 3-year period to provide affordable BRT services. It uses physically separated dual median bus lanes to service multiple stations.

Curitiba. The median busway system was found to be more flexible and affordable than rail and was an integral part of the "structural axis" along which development was encouraged.

Quito. Improved public transport became a political imperative; the need for a "clean" (electric trolley bus) system was essential in view of the city's cultural heritage.

The individual case studies included in Appendix B (available on *CRP-CD-31*, which accompanies this volume) provide additional detail regarding the reasons for implementation within each community.

2.B.3 Features of BRT Systems

The main features of the BRT include dedicated running ways; attractive stations; distinctive, easy-to-board vehicles; off-vehicle fare collection; use of ITS technologies; and frequent all-day service.

Table A-2 in Appendix A shows the BRT features listed above for each of the 26 cities analyzed. The table provides a brief overview of the status of BRT around the world. There is a wide range of BRT services and facilities. These different services and facilities reflect specific community needs and resources. The principal features, listed by system and geographic area, are summarized in Table 7.

Over 80% of the systems profiled have some type of exclusive running ways—either a bus-only road or bus lane. More than 75% provide frequent all-day service, and about 67% have "stations" rather than stops. In contrast, only about 40% have distinctive vehicles (in delineation, type, and livery), and roughly 38% feature some type of ITS application. Only five systems (17%) have off-board fare collection.

Three existing systems have all six basic features: Bogotá's TransMilenio, Curitiba's system, and Quito's Trolebus. Rouen has five features, and several other systems have four. Systems

TABLE 7 Number of facilities with specific features

Feature	US / Canada	Australia / Europe	South America	**Total**	**% of Total**
Dedicated Running Ways	13	5	6	24	83
Stations	12	4	3	19	66
Distinctive Vehicles	7	1	3	11	38
Off-Vehicle Fare Collection	2	0	3	5	17
ITS	7	1	3	11	38
Frequent All-Day Service	11	5	6	22	76
Total Systems Surveyed	**17**	**6**	**6**	**29**	**100**

under development in Boston, Cleveland, and Eugene will also have the six BRT elements.

Within the United States and Canada, 13 of 17 systems have dedicated running ways (bus lanes or busways), 12 have stations, 11 have all-day service, 7 feature ITS elements, and only 1 system (Boston's Silver Line) currently has off-board fare collection. Another one is still being planned.

Running Ways

BRT running ways include operations in mixed traffic, median arterial busways, contra-flow freeway bus lanes, normal-flow freeway HOV lanes, busways on separate rights-of-way, and bus tunnels. Descriptions, characteristics, and costs of running ways are given in Table A-3 in Appendix A for each of the 36 individual facilities in the 26 cities surveyed. These running way features are summarized by geographic region in Table 8.

There is considerable variation among BRT facilities from region to region. Independent busways dominate North American and Australian practice, whereas arterial median busways are used throughout South America. Arterial street bus operations are found in two of the three European case studies. Reserved freeway lanes for buses and carpools are found only in the United States.

Bus tunnels exist in Brisbane and Seattle, and one is being developed in downtown Boston. This represents an important advance in BRT facility development, bringing a key running way feature of rail transit to bus operations. It also overcomes the problems associated with street running in congested downtown areas.

Bus-only roads (busways) exist in Miami, Ottawa, Pittsburgh, Runcorn, and Brisbane. Busways are under development in Hartford and Sydney. Figure 2 shows the West Busway in Pittsburgh.

Curb bus lanes traditionally have been the main type of bus priority treatment in North America and Europe, although they were not reported in the case studies. Despite their advantages in bringing buses curbside and their minimum impact on street traffic flow, curb bus lanes are often avoided because of their uncertain availability and conflicts with deliveries. This is certainly the case in South America, where arterial median busways predominate.

Several systems in the United States and Canada (Honolulu, Los Angeles, and Vancouver) operate largely in mixed traffic. In the case of Los Angeles, this is an interim operation, and bus-only lanes will be selectively incorporated in the future.

Running ways are generally radial, extending to or through the city center. However, Vancouver's Broadway-Lougheed Line provides cross-town service and is anchored by the University of British Columbia in the west. Sydney's northwest suburbs busway will be a circumferential facility.

Bus lanes are typically 11 to 12 feet wide. Shoulders are provided along busways where space exists. At busway stations, roadways are typically widened to about 50 feet to allow for express bus or skip-stop passing. Busway envelopes are about 30 to 50 feet between stations. At stations, the total envelope (four travel lanes, plus station-side platforms) can be as wide as 75 feet. Examples of this are the following:

- The New Britain–Hartford Busway will provide a 50-foot envelope at "staggered," or offset, side platform stations.
- The South Miami–Dade Busway provides a 52-foot roadway at stations plus station platforms.
- The Ottawa Transitway provides two 13-foot lanes and 8-foot shoulders. There is a 75-foot envelope at stations.
- Curitiba's arterial median busway has a 23-foot roadway. The overall envelope, including stations and service roads, is 72 to 85 feet wide.

TABLE 8 Types of facility by region

	US/ Canada	Australia	Europe	South America	Total
Arterial Street					
Mixed Traffic	5	-	-	-	5
Queue Bypass	0	-	1 (1)		1
Curb Bus Lanes	0		1 (2)		1
Median Busway	2 (3)			8	10
Freeways/Separate Rights-of-Way					
Contra-flow Lanes	3				3
HOV Lanes	3				3
Busways	7	3 (1)	1		11
Bus Tunnels	2				2
TOTAL	**22**	**3**	**3**	**8**	**36**

(1) Includes O-Bahn and bus tunnel as part of one busway
(2) Optically Guided Bus
(3) Once system includes an electronically guided vehicle

Figure 2. West Busway, Pittsburgh.

Figure 3 shows the typical median busway design used in South American cities.

Stations

BRT station characteristics and features are given in Table A-4 and Table A-5, which are located in Appendix A. Table A-4 shows the spacing, length, bypass capabilities, platform heights, and fare collection practices. Table A-5 describes the reported design features and amenities.

Spacing. Station spacing along freeways and busways ranges upward from about 2,200 feet along Boston's Silver Line to several miles along the Adelaide O-Bahn and the San Bernardino Freeway. The South Miami–Dade Busway has a spacing of almost 2,900 feet; the Pittsburgh busways average 4,200 feet; the Brisbane busway averages 5,540 feet; the Ottawa Transitway system averages 6,900 feet; and the San Bernardino Busway exceeds 21,000 feet.

BRT station spacing along arterial streets ranges upward from about 1,000 feet in Porto Alegre, 1,200 feet in Cleveland, and 1,400 feet in Curitiba to over 4,000 feet along Vancouver's "B" Lines and Los Angeles' Metro Rapid bus service.

This spacing, ranging from approximately 125 feet in urban areas to 5,280 feet in suburban areas, is similar to LRT and metro practice.

Locations. Stations are placed curbside when buses operate in mixed traffic, as in Los Angeles and Vancouver. Stations are typically located on the outside of the roadway along arterial medians and busways. However, the Bogotá system, a section of the Quito Trolebus, and Curitiba's "direct" service have center island platforms with commensurate use of left-side doors.

Passing Capabilities. Busways widen from two to four lanes to enable express buses to pass around vehicles making stops. In staggered stop situations, busways typically widen to three lanes. The median arterial busways in South American cities also provide passing lanes for buses; usually, station platforms are offset to minimize the busway envelope, thereby resulting in lane changes (shifts) by buses. Bogotá's median busway has continuous express (passing) lanes. Cleveland will operate express buses on parallel streets, thereby obviating the need for passing lanes at median busway stations.

The Brisbane and Ottawa busways have barriers between opposing directions of travel at stations to prevent at-grade pedestrian crossings, as shown in Figure 4. Pittsburgh has barriers as well as raised curbs with designated crosswalks. Miami merely designates desired crossing locations, as will the planned New Britain–Hartford Busway.

Platform Length. Station platform length varies depending on bus volumes and the lengths of the vehicles operated. Stations typically accommodate two to three buses, although busy stations may accommodate four to five vehicles. Boston's Silver Line, for example, will have 220-foot-long platforms that can simultaneously handle three 60-foot articulated buses. Because of the enormous volumes it carries, Bogotá's TransMilenio busway has bus stations ranging up to 500 feet long.

Platform Height. Most new BRT stations have low platforms because many will be served by low-floor buses. However, three systems in South America—Bogotá's TransMilenio, Quito's Trolebus, and Curitiba's all-stop and "direct" services—provide high platforms to allow level boarding and

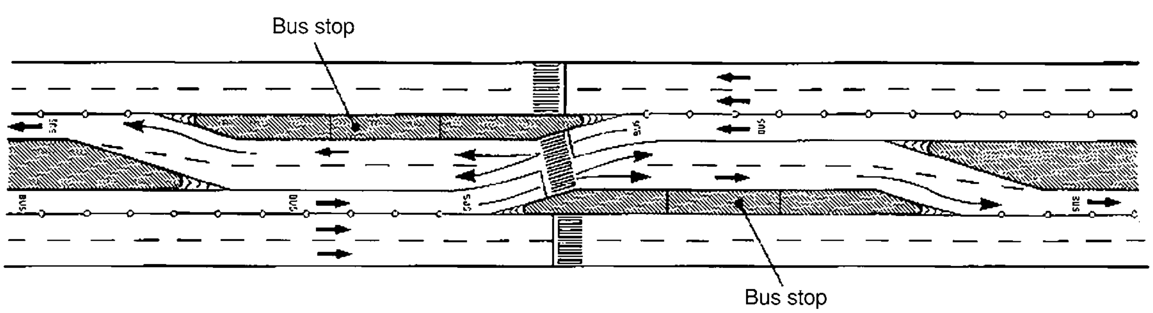


Figure 3. Typical median busway design, South America.

Figure 4. Barrier between opposing directions of travel at Ottawa Transitway station.

Figure 6. Bi-articulated bus median, Curitiba.

alighting of passengers from high-floor vehicles, as shown in Figures 5 and 6. Guided vehicles such as the Irisbus Civis vehicle used in Rouen or buses with drop-down bridges, such as those used in Bogotá, Quito, and Curitiba, are required for floor-to-platform boarding and alighting.

Fare Collection. Bogotá, Curitiba, and Quito have off-vehicle fare collection in conjunction with their high-platform stations, similar to metrorail systems. The stations function essentially like those for rail rapid-transit lines. Prepayment, along with multidoor use of buses, reduces dwell times; this is apparent in the reduction of 20 seconds per stop in Curitiba. In Rouen, the barrier-free honor fare system, similar to that used in the city's LRT system, facilitates multiple-door boarding. In other cities with high BRT passenger volumes (e.g., Ottawa and Pittsburgh), the use of fare passes allows at least two-stream boarding through front and back doors.

Design Features. Stations in the case study systems provide a broad spectrum of features and amenities depending on location, climate, type of facility, and available space. Some are simple, attractive canopies, as can be seen along the South Miami–Dade Busway or Los Angeles's Metro Rapid lines, shown in Figure 7. Others, such as those along Brisbane's South East Busway, provide distinct and architecturally distinguished designs, as well as a full range of pedestrian facilities and conveniences, as shown in Figure 8. The "high-platform" stations in Bogotá, Curitiba, and Quito contain extensive space for fare payment. Curitiba's tube stations have become an internationally recognized symbol. The Los Angeles Metro Rapid bus stations feature real-time bus arrival information.

Overhead pedestrian walks connect opposite sides of stations in Brisbane and Ottawa, as well as busy stations in Pittsburgh. In some situations, access to both platforms is provided from roadway crossings over the busway.

Vehicles

BRT vehicles range from conventional buses to distinctive, dedicated BRT vehicles. Key characteristics of BRT vehicles for selected systems are shown in Table A-6 in Appendix A.

Figure 5. Trolebus station, Quito.

Figure 7. Los Angeles Metro Rapid bus station.

Figure 8. South East Busway station, Brisbane.

Body Style. Vehicle body styles include the standard (40-foot) bus, articulated (60-foot) buses, and, in Curitiba, bi-articulated buses. Some double-deck buses operate in Leeds, and Houston's BRT service uses over-the-road intercity coaches. It is important to note that almost every city cited in the United States and Canada, except Los Angeles and Vancouver, operates or will operate articulated vehicles. Figure 9 shows the dual-mode articulated bus that will be used in Boston's South Pier Transitway. Rouen, Boston, and Cleveland operate or plan to operate special BRT vehicles rather than conventional buses.

Propulsion. Standard diesel buses predominate; however, a trend in North America is to use "clean" vehicles such as CNG or hybrid diesel-electric vehicles (as in Los Angeles and Cleveland). Seattle and Boston operate or will operate dual-mode electric trolley and diesel or CNG buses. The Irisbus Civis vehicle used in Rouen, France, is a "new design" diesel or CNG electric vehicle with train-like features and the ability to be guided. This vehicle is shown in Figure 10.

Figure 9. Dual-mode articulated bus.

Figure 10. Irisbus Civis vehicle used in Rouen.

Floor Height. An increasing number of systems operate low-floor vehicles to make passenger boarding and alighting easier. Buses in Bogotá, Curitiba, and Quito have high-platform boarding and alighting. Although these vehicles reduce passenger service times, their operation is limited to the BRT lines with high-platform stations. This dramatically reduces their operating flexibility.

Door Arrangements. The need for better door arrangements on buses used in BRT service is increasingly recognized. Existing door arrangements have been a major constraint to shortening dwell times on many North American bus systems. Many articulated buses have three double-stream doors and one single-stream door. The bi-articulated buses used in Curitiba have five sets of doors. The rail-like articulated Irisbus Civis vehicle has four doors.

Doors are generally located on the right side for North American and French systems and on the left side for buses operating in Australia and Great Britain, although left-hand doors are available from many manufacturers (e.g., Irisbus and Gillig) to support center platform stations. The "direct buses" in Curitiba, which operate along one-way arterials, have left-side doors, as do buses operating in Bogotá. Some of the buses operating in Sao Paulo have doors on both sides to better serve various platform arrangements.

Design Features. Several BRT systems have dedicated vehicles with special identity and livery. Bogotá, Curitiba, and Los Angeles use red buses for their BRT services. Honolulu, Quito, and Vancouver have distinctively striped buses. Rouen's Irisbus Civis vehicles and Bogotá's TransMilenio buses have modernistic rail-like styling and a futuristic appearance and could serve as prototypes for future BRT vehicle designs. Rouen's Irisbus Civis buses have a minimum aisle width of 34 inches end to end.

ITS

Selected applications of ITS technologies used in BRT operations are set forth in Table A-7 in Appendix A. The applications shown cover (1) automatic vehicle location (AVL) systems; (2) passenger information systems (e.g., automated station announcements on vehicles, real-time information at stations); and (3) traffic signal preference/priorities.

BRT systems using AVL systems include Boston (under construction), Hartford (under development), Los Angeles, Vancouver, Brisbane, Sydney (proposed), and Bogotá.

Systems with passenger information systems include Boston (under construction), Hartford (under development), Ottawa, Pittsburgh (some buses), Vancouver, Brisbane, Los Angeles's Metro Rapid bus, and Curitiba.

Systems having traffic signal timing priorities or special bus phases include Cleveland (under development), Los Angeles, Vancouver, and Rouen. The Metro Rapid lines in Los Angeles, for example, can get up to 10 seconds of additional green time when buses arrive at a signalized intersection. However, at major crossroads, advancing or extending the green time for buses can take place only every other cycle. Bus signal preemption along South Miami–Dade Busway was removed because of increases in accidents. The Brazilian cities of Porto Alegre and Sao Paulo have bus platoon dispatching systems (Commonor) that are used to increase bus and passenger throughput.

Service Patterns

The types of BRT service provided in the various BRT case studies are shown in Table A-8 in Appendix A. The specific patterns reflect the types of running ways and vehicles utilized. Most systems provide express or limited-stop services laid over an all-stop (or local) service that operates like an LRT line. Some also have feeder bus lines that serve selected stations.

Busways—either along separate rights-of-way or within street medians—can have basic "all-stop" service with an overlay of express operations during peak periods. In a few cases, such as Cleveland and Curitiba, the express service is or will be provided along nearby parallel streets. BRT operations in mixed traffic—as in Honolulu, Los Angeles, New York City, and Vancouver—provide limited-stop service. Local bus service is also operated along the streets, as part of the normal transit service. Rouen's BRT system also provides limited-stop service along arterial streets.

The bus tunnels in Boston and Seattle are located in downtown areas. All buses make all stops in the tunnels.

The "guided buses" in Leeds and Eugene essentially provide all-stop service. Quito's Trolebus service also stops at all stations.

Buses operating in New York City's reverse-flow expressway bus lanes run express and do not make intermediate stops. Buses using median expressway lanes in Charlotte's and Houston's HOV lanes also operate nonstop; there are no intermediate stops. However, in Houston, there are a number of routes that exit the HOV lanes on dedicated bus ramps, enter transit centers or park-and-ride lots to drop off or pick up passengers.

In most systems, the BRT service extends beyond the limits of busways or bus lanes. This flexibility is an important advantage of BRT as compared with rail transit. However, three BRT systems in South America operate only within the limits of the special running way, mainly because of door arrangements, station platform heights, and/or propulsion systems. These systems, including Bogotá's TransMilenio, Curitiba's median bus service, and Quito's Trolebus, actually function as though they were rail rapid-transit lines.

2.B.4 Performance

Performance characteristics of the existing BRT systems, as measured by passengers carried and travel speeds, are shown in Table A-9 in Appendix A. Performance varies widely, reflecting factors such as facility location, size of the urban area, and type of facility (e.g., off-street or arterial).

Weekday Riders

The weekday ridership reported for existing systems in North America and Australia ranged from about 1,000 riders in Charlotte to 40,000 or more in Los Angeles, Seattle, and Adelaide. Specific ridership figures are shown in Table 9.

Daily ridership in South American cities is substantially higher. Reported values for specific facilities include 150,000 riders per day in Quito, 230,000 in Sao Paulo, and about 600,000 in Bogotá. Reported system riders exceed 1,000,000 in Belo Horizonte, Curitiba, and Porto Alegre.

Peak-Hour Bus Flows

Where there are no intermediate stops, peak-hour, peak-direction bus flows on dedicated freeway lanes can exceed

TABLE 9 Ridership figures for selected BRT systems

Bus Subways	Seattle	46,000
Busways	Ottawa	200,000
	Brisbane	60,000
	Pittsburgh	48,000
	Adelaide	30,000
	San Bernardino (Los Angeles)	18,000
	Miami	12,000
	Harbor (Los Angeles)	9,400
	Charlotte	1,000
Arterial Streets	Wilshire (Los Angeles)	55,000
	Vancouver	14,000–24,000
	Ventura (Los Angeles)	10,000

650 buses per hour (e.g., on the New Jersey approach to the Lincoln Tunnel and the Port Authority of New York/New Jersey Midtown Bus Terminal.) The Ottawa Transitway system reports bus volumes of 180 to 200 buses per hour along downtown bus lanes. These volumes result from high use of fare passes, an honor fare system on the Busway All-Stop routes, and use of multidoor articulated buses. Over 140 buses per hour use the busiest section of Brisbane's South East Busway.

Peak-hour flows of over 100 buses per hour are found in the contra-flow bus lanes on New York City's Long Island Expressway and Gowanus Expressway. Most other BRT facilities in the United States and Australia have less than 100 buses per hour. Flows of about 50 to 70 buses per hour are typical.

The South American arterial median bus lanes that have passing capabilities at stations carry as many as 300 buses per hour one way at the maximum load point.

Peak-Hour, Peak-Direction Riders

Peak-hour passenger volumes carried past the maximum load points exceed 25,000 on the approach to the Lincoln Tunnel in New York, on Bogotá's TransMilenio four-lane busway, and along the Farrapos Busway in Porto Alegre. Peak-hour passenger volumes approach 20,000 on median busways in Sao Paulo and Porto Alegre. Ridership in Quito, Ottawa, and Curitiba is in the 8,000–12,000 range. Brisbane's South East Busway carries 9,500 people one way in approximately 150 buses during the peak hour. Its capacity has been estimated at 11,000 persons per hour. The ridership seen in the international case studies equals or exceeds the number of LRT and metro passengers carried in most U.S. and Canadian cities.

Speeds

BRT operating speeds depend upon the type of running way and service pattern. Where buses run nonstop on reserved freeway lanes, revenue speeds of 40 to 50 miles per hour are common. When the service patterns include stops on reserved or dedicated lanes, buses generally average 20 to 30 miles per hour, depending on top spacing and dwell times. These speeds are comparable with LRT speeds for the same type of operating environment. The slower speeds recorded along Miami's busway reflect stops and traffic signal delays at signalized intersections along the busway.

Average speeds for BRT operations along arterial streets in the United States and Canada range from 8 to 14 miles per hour in New York City to 15 miles per hour along Wilshire Boulevard and 19 miles per hour along Ventura Boulevard in Los Angeles.

"Express" operations along Curitiba's one-way streets and Bogotá's TransMilenio busway are approximately 19 miles per hour. Buses making all stops along median busways in South America average 11 to 14 miles per hour. These speeds are low when compared with BRT operations in the United States and Canada. However they represent dramatic improvements over local bus speeds and are often faster than automobile speeds.

2.B.5 Benefits of BRT

BRT systems have achieved important benefits in terms of travel time savings, increased ridership, land development impacts, and improved safety.

Travel Time Savings

Reported travel time savings resulting from BRT operations are shown in Table A-10 in Appendix A. These savings are shown as the percent change in speeds, the total time saved in minutes, and the minutes saved per mile of travel.

Travel time reductions resulting from the introduction of BRT services have sometimes exceeded 40%. Bus operations in exclusive freeway lanes or busways have achieved travel time savings of 47% in Houston, 44% in Pittsburgh, 38% in Los Angeles, and 32% in Adelaide compared with local bus routes. Seattle's bus tunnel has achieved a 33% reduction in bus travel times for the CBD portion of bus routes.

BRT service along arterials has achieved travel time savings of 23% to 28% in Los Angeles, 29% in Porto Alegre, and 32% in Bogotá compared with the fastest alternative bus services. The time savings in Los Angeles are impressive in that buses operate in mixed traffic. These time savings have been achieved by increasing the spacing between stops and by providing up to 10 seconds of additional green time at signalized intersections using a signal priority system.

Total time savings range from 5 minutes at Seattle's bus tunnel to over 20 minutes along Pittsburgh's East and West

Busways. Most facilities achieve time savings of 2 to 3 minutes per mile.

Busways and reserved bus lanes on freeways that bypass traffic backup on approaches to river crossings save up to 7.5 minutes per mile. Busways on partially grade-separated rights-of-way generally save 2 to 3 minutes per mile over the previous bus service. BRT lines on arterial streets typically save 1 to 2 minutes per mile. The savings are greatest where the previous bus routes experienced major congestion.

Ridership Increases

Reported increases in bus riders are given in Table A-11 in Appendix A. The increases reflect the provision of expanded transit service, reduced travel times, improved facility identity, and overall population growth. Collectively, the increases clearly demonstrate that BRT can attract and retain new, even discretionary, riders.

Some evidence suggests that many of the new riders were previously motorists and that improved bus service results in more frequent travel. In Houston, for example, up to 30% of the riders were new riders, and up to 72% were diverted from automobiles. In Los Angeles, the Metro Rapid bus service, which operates in mixed traffic, had about a 33% increase in riders. The increase was made up of new riders, riders diverted from other corridors, and people who rode transit more often. In Vancouver, 20% of new riders previously used automobiles, 5% represented new trips, and 75% were diverted from other bus lines.

Adelaide's Guided Busway reported a 76% gain in ridership at a time when overall system ridership declined by 28%. Brisbane's South East Busway reported over a 40% gain in riders during the first 6 months of service and a reduction of 375,000 automobile trips annually.

Operating and Environmental Benefits

The travel time savings associated with buses operating on their own rights-of-way have also achieved operating costs and safety and environmental benefits, as shown in Table 10. All cost savings are reported in U.S. dollars.

The Ottawa Transitway requires 150 fewer buses than if the Transitway system did not exist, resulting in savings of roughly $49 million in vehicle costs and $19 million in annual operating costs.

Seattle's bus tunnel has reduced surface street bus volumes by 20%. Buses using the tunnel also had 40% fewer accidents than in mixed-traffic operations.

Bogotá's TransMilenio busway had 93% fewer fatalities. In addition, a 40% drop in pollutants was recorded during the first 5 months of operation.

Curitiba uses 30% less fuel per capita for transportation than other major Brazilian cities. This has been attributed in part to the success of the BRT system.

Land Development Benefits

Like other rapid rail transit modes, BRT stations can provide a focal point for transit-oriented development. Reported land development benefits and other benefits are shown in Table 10. Ottawa reported over $675 million in new construc-

TABLE 10 Benefits, selected BRT systems

SYSTEM	LAND DEVELOPMENT BENEFITS
Pittsburgh East Busway	59 new developments within a 1500-ft radius of station. $302 million in land development benefits, of which $275 million was new construction. 80% is clustered at station.
Ottawa Transitway System	$1 billion in Canadian dollars ($C) in new construction at Transitway stations.
Adelaide Guided Busway	Tea Tree Gully area is becoming an urban village.
Brisbane South East Busway	Up to 20% gain in property values near Busway. Property values in areas within 6 miles of station grew 2 to 3 times faster than those at greater distances.
	OTHER BENEFITS
Ottawa Transitway	150 fewer buses, with $58 million ($C) savings in vehicle costs and $28 million ($C) in operating costs.
Seattle Bus Tunnel	20% reduction in surface street bus volumes. 40% fewer accidents on tunnel bus routes.
Bogotá TransMilenio Median Busway	93% fewer fatalities. 40% drop in pollutants.
Curitiba Median Busway	30% less fuel consumption per capita.

tion around Transitway stations. Pittsburgh reported $302 million in new or improved developments along the East Busway stations. Values of property located near Brisbane's South East Busway grew two to three times as fast as the values of property located at greater distances. These impacts are similar to those experienced along rail transit lines.

In the cases of several of the BRT systems studied, local governments implemented land use planning policies that encouraged development near BRT facilities. In the Ottawa-Carleton region, major developments such as regional shopping centers are required to locate near the Transitway. In Curitiba, the arterial median busways are integral parts of the structural axes along which high-density development has been fostered.

2.B.6 Costs

Costs for BRT systems vary widely depending on the BRT elements being implemented (e.g., running ways, vehicles, etc.) and the location, type, and complexity of construction. Development costs for the BRT systems in the case studies are shown in Table A-12 in Appendix A. For the implemented systems, these costs reflect those incurred at time of construction. The costs per mile of facility are also shown. A comparison of the costs shows the following:

- Costs for bus tunnels range from about $200 to $300 million per mile, including stations.
- Costs for busways on their own rights-of-way display a wide range, depending upon the year they were built and ease of construction. The values cited range from about $6 to $7 million in Los Angeles, Miami, and Pittsburgh (South Busway) to about $20 million per mile for the East Busway in Pittsburgh and the recently completed South East Busway in Brisbane. The high cost of Pittsburgh's West Busway—about $53 million per mile—was due to the hilly terrain traversed, a major tunnel rehabilitation, and an expensive freeway interchange at the outer terminus of the busway.
- Costs for arterial street median busways have been reported as about $1.5 million per mile in Curitiba, $5 to $8 million per mile in Bogotá and Quito, and an estimated $29 million per mile in Cleveland.
- Costs for mixed-traffic operation have generally been less than costs for BRT systems with dedicated running ways. The costs reported for guided bus systems include $2.4 million per mile of guideway in Leeds, $7 million per mile in Rouen, and less than $8 million per mile expected in Las Vegas.

Information on busway maintenance costs was only available for Pittsburgh's East Busway. These costs averaged $110,000 per mile per year for 7 miles.

Operating costs for BRT service are influenced by wage rates and work rules, fuel and electricity costs, operating speeds, and ridership. Operating costs for Pittsburgh's East Busway and South Busway (1989) averaged $0.52 per passenger trip. Costs per trip for light rail lines in Buffalo, Pittsburgh, Portland, Sacramento, and San Diego averaged $1.31; the cost range was from $0.97 (San Diego) to $1.68 (Sacramento). These comparisons suggest that BRT can cost less per passenger trip and per mile than LRT, depending on the situation (*16*).