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This reference was prepared for the Office of Research, Demonstration and Innovation of the Federal Transit Administration (FTA). The report is intended to support evaluation of bus rapid transit concepts as one of many options during the initial project planning and development. This report presents a comprehensive summary of applications of BRT elements in the United States and in selected sites around the world. Information on the first wave of BRT projects to be implemented in the United States is presented to show the broad range of applications of key elements of BRT – running ways, stations, vehicles, fare collection, intelligent transportation systems (ITS), and service and operating plans. This report also presents performance of BRT systems and discusses how combinations of BRT elements contribute to transit system performance, including reducing travel times, improving reliability, providing identity and a quality image, improving safety and security, and increasing capacity. Some important benefits of integrated BRT systems are presented, including transportation system benefits (increasing ridership, and improving capital cost effectiveness and operating efficiency) and community benefits (transit-supportive development and environmental quality).

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SOURCES OF INFORMATION

This report draws from a variety of sources of information. Reports and research documents are cited in footnotes and in the bibliography (Appendix A). In addition to sources cited, staff members at agencies provided valuable up-to-date system information on experience with elements, performance, and benefits at their respective systems and photographs.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

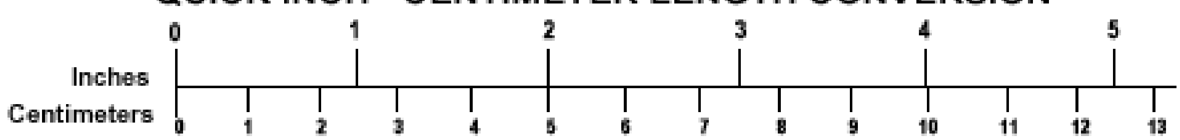
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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EXECUTIVE SUMMARY

The ***Characteristics of Bus Rapid Transit for Decision-Making (CBRT)*** report was prepared to provide transportation planners and decision makers with basic information and data to support the development and evaluation of bus rapid transit concepts as one of many options during alternatives analyses and subsequent project planning. This report provides information on BRT systems in a single, easy to use reference tool for transportation planners in selecting from the large array of BRT elements and integrating them into comprehensive systems.

The CBRT report explores BRT through three different perspectives. First, six major elements of BRT are presented along with their respective features and attributes. Second, these BRT elements are related to attributes of system performance. Finally, the benefits of BRT systems are discussed. This structure suggests relationship between BRT elements, system performance and system benefits. The choice of BRT elements determine system performance. Performance characteristics, together with individual elements, drive how benefits are generated.

EXPERIENCE WITH BRT ELEMENTS

Experience in the United States suggests that implementation of more complex BRT system elements is just beginning. Implementation of running ways, stations, and vehicles suggest a wide variety of applications. Some of the more quickly implemented projects demonstrated the least amount of investment in BRT system elements.

BRT Element		Experience in the United States
Running Way ▪ Running Way Segregation ▪ Running Way Marking ▪ Guidance (Lateral)		▪ BRT systems in the United States have incorporated all types of running ways – mixed flow arterial (Los Angeles, Honolulu), mixed flow freeway (Phoenix), dedicated arterial lanes (Boston, Orlando), at-grade transitways (Miami), and fully grade-separated surface transitways (Pittsburgh), and subways (Seattle, Boston late 2004). ▪ The only application of running way guidance was the precision docking for Las Vegas MAX with optical guidance. ▪ Use of running way markings to differentiate BRT running ways and articulated brand identity was rare.

BRT Element		Experience in the United States
Stations ▪ Station Type ▪ Platform Height ▪ Platform Layout ▪ Passing Capability ▪ Station Access		▪ The level of station design correlates strongly with the level of running way segregation. Systems with designated lanes on arterials or segregated transitways had stations with higher sophistication and more amenities. ▪ Only one system in the United States has level boarding platforms (Las Vegas MAX). ▪ Real-time schedule and/or vehicle arrival information and communications infrastructure such as public telephones and emergency telephones are starting to be installed in systems.
Vehicles ▪ Vehicle Configuration ▪ Aesthetic Enhancement ▪ Passenger Circulation Enhancement ▪ Propulsion		▪ Early BRT systems used standard vehicles that were often identical to the rest of a particular agency's fleet. Systems, such as Los Angeles Metro Rapid, AC Transit's Rapid Bus, and Boston's Silver Line, are phasing in operation of 60-foot articulated buses as demand grows. ▪ The use of vehicle configurations or aesthetic enhancements to differentiate BRT is gaining momentum. In addition to differentiated liveries and logos, agencies are procuring Stylized and Specialized BRT vehicles. Las Vegas provides the first use of a Specialized BRT Vehicle.
Fare Collection ▪ Fare Collection Process ▪ Fare Transaction Media ▪ Fare Structure		▪ Alternate fare collection processes are rare in the United States, with the only proof-of-payment system associated with the Las Vegas MAX system. Variations on proof-of-payment such as free downtown zones and pay-on-exit are used in Orlando, Seattle, and Pittsburgh. ▪ Electronic fare collection using magnetic-stripe cards or smart cards is slowly being incorporated into BRT systems, but as part of agency-wide implementation rather than BRT-specific implementation. Smart cards are more common.
Intelligent Transportaiton Systems ▪ Vehicle Prioritization ▪ Driver Assist and Automation Technology ▪ Operations Management Technology ▪ Passenger Information ▪ Safety and Security Technology ▪ Support Technologies		▪ The most common ITS applications include Transit Signal Priority, Advanced Communication Systems, Automated Scheduling and Dispatch Systems, and Real-Time Traveler Information at Stations and on Vehicles. ▪ Installation of Security Systems such as emergency telephones at stations and closed circuit video monitoring is rare, but increasing as newer, more comprehensive systems are implemented.
Service and Operating Plans ▪ Route Length ▪ Route Structure ▪ Service Span ▪ Frequency of Service ▪ Station Spacing ▪ Method of Schedule Control		▪ Implementations of BRT generally followed principles of greater spacing between stations, all-day service spans and frequent service. ▪ Systems that use exclusive transitways (Miami-Dade's at-grade South Busway and Pittsburgh's grade-separated transitways) are operated with integrated networks of routes that include routes that serve all stops and a variety of feeders and expresses with integrated off-line and line-haul operation.

EXPERIENCE WITH BRT SYSTEM PERFORMANCE

System performance for BRT systems is assessed according to five key attributes – travel time, reliability, identity and image, safety and security, and capacity. Each of the BRT system elements has different effects on system performance.

A summary of which elements affects each attribute of system performance is presented below.

	System Performance				
	Travel Time Savings	Reliability	Identity and Image	Safety and Security	Capacity
RUNNING WAY					
Running Way Segregation	●	●	●	●	●
Running Way Marking			●		
Running Way Guidance	●		●	●	
STATIONS					
Station Type	●		●	●	●
Platform Height	●	●	●	●	●
Platform Layout	●	●			●
Passing Capability	●	●			●
Station Access			●	●	
VEHICLES					
Vehicle Configurations	●	●	●	●	●
Aesthetic Enhancement			●	●	
Passenger Circulation Enhancement	●	●	●	●	●
Propulsion Systems	●		●		
FARE COLLECTION					
Fare Collection Process	●	●	●		●
Fare Transaction Media	●	●	●	●	●
Fare Structure	●		●		●
INTELLIGENT TRANSPORTATION SYSTEMS					
Vehicle Prioritization	●	●	●		●
Driver Assist and Automation Technology	●	●	●	●	●
Operations Management	●	●		●	●
Passenger Information	●	●	●	●	
Safety and Security technology				●	
Support Technologies					●
SERVICE AND OPERATING PLANS					
Route Length		●			
Route Structure	●		●		
Span of Service		●			
Frequency of Service	●	●		●	●
Station Spacing	●	●			

BRT system performance can be assessed based on the experience of ten BRT systems across the United States:

- Silver Line, Boston, MA
- Neighborhood Express, Chicago, CA
- CityExpress!, Honolulu, HI,
- MAX, Las Vegas, NV
- Metro Rapid, Los Angeles, CA
- South Dade Busway, Miami-Dade, FL
- Rapid Bus San Pablo Corridor, Oakland, CA
- LYMMO, Orlando, FL
- Busways (West, East and South), Pittsburgh, PA
- Rapid, Phoenix, AZ

The experience suggests that there are concrete improvements to travel time, reliability, and capacity as well as perceptions of improvements in safety and security and image and identity.

Travel Time

With respect to total BRT travel times, BRT projects with more exclusive running ways generally experienced the greatest travel time savings compared to the local bus route. Exclusive transitway projects operated at a travel time rate of 2 to 3.5 minutes per mile (between 17 and 30 miles per hour). Arterial BRT projects in mixed flow traffic or designated lanes operated between 3.5 and 5 minutes per mile (between 12 and 17 miles per hour). Performance in reliability also demonstrated a similar pattern.

Reliability

As expected, systems with more exclusive transitways demonstrated the most reliability and the least schedule variability and bunching. The ability to track reliability changes has been limited by the fact that most transit agencies do not regularly measure this performance attribute. Passenger surveys, however, indicate that reliability is important for attracting and retaining passengers. New automated vehicle location systems, may allow for the objective and conclusive measurement of reliability.

Image and Identity

Performance in achieving a distinct brand identity for BRT has been measured by in-depth passenger surveys. The more successful BRT systems have been able to achieve a distinct identity and position in the respective region’s family of transit services. BRT passengers generally had higher customer satisfaction and rated service quality higher for BRT systems than for their parallel local transit services.

Safety and Security

Data measuring the difference in safety and security of BRT systems as compared with the rest of the respective region's transit system have not been collected. Drawing conclusions about the efficacy of BRT elements in promoting safety and security is therefore premature. Data from Pittsburgh suggest that BRT operations on exclusive transitways have significantly fewer accidents per unit (vehicle mile or vehicle hour) of service than conventional local transit operations in mixed traffic. Customer perceptions of "personal safety" or security reveal that customers perceive BRT systems to be safer than the rest of the transit system.

Capacity

For virtually all BRT systems implemented in the United States, capacity has not been an issue. To date, none of them have been operated at their maximum capacity. On all systems, there is significant room to expand operated capacity by operating larger vehicles, higher frequencies, or both.

EXPERIENCE WITH BRT SYSTEM BENEFITS

The benefits of BRT system implementation are now being felt. While the most tangible benefit is additional ridership, cost effectiveness and operating efficiencies as well as increases in transit-supportive land development and environmental quality are also closely linked to the implementation of BRT systems.

Ridership

There have been significant increases in transit ridership in virtually all corridors where BRT has been implemented. Though much of the ridership increases have come from passengers formerly using parallel service in other corridors, passenger surveys have revealed that many trips are new to transit, either by individuals who used to drive or be driven, or individuals who used to walk, or by individuals who take advantage of BRT's improved level of service to make trips that were not made previously.

Aggregate analyses of ridership survey results suggest that the ridership increases due to BRT implementation exceed those that would be expected as the result of simple level of service improvements. This implies that the identity and passenger information advantages of BRT are attractive to potential BRT customers. Ridership gains of between 5 and 25% are common. Significantly greater gains, such as 85% in Boston's Silver Line represent the potential for BRT.

Capital Cost Effectiveness

BRT demonstrates relatively low capital costs per mile of investment. While recently implemented BRT systems have focused on less capital-intensive investments, more capital intensive investments will begin service in the next few years. Depending on the operating environment, BRT systems are able to achieve service quality improvements (such as travel time savings of 15 to 25 percent and increases in reliability) and ridership gains that compare favorably to the capital costs and the short amount of time to implement BRT systems. Furthermore, BRT systems are able to operate with lower ratios of vehicles compared to total passengers.

Operating Cost Efficiency

BRT systems are able to introduce higher operating efficiency and service productivity into for transit systems that incorporate them. Experience shows that when BRT is introduced into corridors and passengers are allowed to choose BRT service, corridor performance indicators (such as passengers per revenue hour, subsidy per passenger mile, and subsidy per passenger) improve. Furthermore, travel time savings and higher reliability enables transit agencies to operate more vehicle miles of service from each vehicle hour operated.

Transit-Supportive Land Development

In places where there has been significant investment in transit infrastructure and related streetscape improvements (e.g., Boston, Pittsburgh, and Ottawa and Vancouver in Canada), there have been significant positive development effects. In some cases, the development has been adjacent to transit to the transit facility, while in other places the development has been integrated with the transit stations. Experience is not yet widespread enough to draw conclusions on the factors that would result in even greater development benefits from BRT investment, although the general principle that good transit and transit-supportive land uses are mutually reinforcing should hold.

Environmental Quality

Documentation of the environmental impacts of BRT systems is rare. Experience does show that there is improvement to environmental quality due to a number of factors. Ridership gains suggest that some former automobile users are using transit as a result of BRT implementation. Transit agencies are serving passengers with fewer hours of operation, potential reducing emissions. Most importantly, transit agencies are adopting vehicles with alternative fuels, propulsion systems, and pollutant emissions controls.

PROGRESS WITH DOCUMENTING BRT EXPERIENCE

The experience with BRT as of 2004 represents significant progress since the launch of FTA's BRT Initiative and individual project initiatives at the local level. There has been a long history of individual elements of BRT systems. Recently, however, BRT systems are being integrated much more comprehensively and in ways that are more meaningful and understandable for passengers and non-passengers alike. These integrated systems are being implemented with greater attention to a broader array of objectives. In addition to improving travel time and capacity, other objectives such as reliability, safety and security, and identity and image are motivating the integration of additional elements such as advanced vehicles and more elaborate stations into BRT systems. Ridership gains of between 5 and 25% are common. Furthermore, benefits such as transit-supportive development, environmental quality, capital cost effectiveness, and operating efficiency, are being realized and measured more concretely.

The experience with BRT is off to a positive start with exemplary projects serving as models for future projects implemented by peer agencies. This first wave of projects includes many systems operating with conventional vehicles mixed-flow arterial traffic or exclusive transitways. The years 2005 and 2006 will see more integration of station design, advanced vehicles, fare collection, and ITS into BRT. Additional projects to begin service will include:

- Orange Line (Los Angeles)
- Euclid Corridor (Cleveland)
- Phase I BRT Corridor (Eugene, OR)
- Hartford - New Britain Busway (Hartford, CT)

Documenting these projects and extended experience with existing projects in future editions of **Characteristics of Bus Rapid Transit for Decision-Making (CBRT)** will help to demonstrate the longer-term performance and benefits of BRT.

1.0 INTRODUCTION: THE NEED FOR AND PURPOSE OF CHARACTERISTICS OF BUS RAPID TRANSIT FOR DECISION-MAKING

One of Federal Transit Administration's (FTA) objectives is to provide local and state officials with the information they need to make informed transportation investment decisions. With this objective in mind, the ***Characteristics of Bus Rapid Transit for Decision-Making (CBRT)*** report was prepared. It provides transportation planners and decision makers with basic information and data to support the development and evaluation of bus rapid transit concepts as one of many options during alternatives analyses and subsequent project planning. This report describes the physical, operational, cost, performance and potential benefits of BRT's constituent elements both individually and combined as integrated systems. Its intended audience includes urban transportation professionals and officials involved in developing and evaluating high performance transit systems of which BRT is one alternative.

1.1 WHAT IS BRT?

BRT Implementation Guidelines, defined BRT as:

> "A flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity."[1]

This definition highlights BRT's flexibility and the fact that it encompasses a wide variety of applications, each one tailored to a particular set of travel markets and physical environments. BRT's flexibility derives from the fact that BRT vehicles (e.g., buses, specialized BRT vehicles) can travel anywhere there is pavement and the fact that BRT's basic service unit, a single vehicle, is relatively small compared to rail and train based rapid transit modes. A given BRT corridor application might encompass route segments where vehicles operate on both mixed traffic and where they operate on a dedicated, fully grade-separated transitway with major stations.

BRT applications can combine various route segments such as the above to provide a single-seat, no-transfer service that maximizes customer convenience. Unlike other rapid transit modes where basic route alignment and station locations are constrained by right of way availability, BRT can be tailored to the unique origin and destination patterns of a given

[1] Levinson et al., **Bus Rapid Transit - Implementation Guidelines**, *TCRP Report 90-Volume II*

corridor's travel market. As the spatial nature of transit demand changes, BRT systems can adapt to these dynamic conditions.

Many of the concepts at the heart of BRT have been in use for decades. Dedicated transitways/busways, limited-stop and express services and exclusive bus lanes have become part of the transit planning vocabulary because they have enhanced speed and reliability and thus encouraged transit usage; however, there is uncertainty among elected officials and even some transit professionals about what BRT is and how it differs from conventional bus services and systems. This question is difficult to answer, in part because the options available for each BRT element are so extensive that there are an infinite variety of integrated BRT systems. BRT's inherent flexibility means that no two BRT systems will look exactly the same within a given region let alone between two different metropolitan areas.

Fortunately, there is an extensive body of information and data describing each of BRT's constituent elements and a growing body of literature on the cumulative impacts of packaging multiple elements into integrated BRT systems. This report combines both types of information in a single, easy to use reference tool for transportation planners generating evaluation criteria for use in selecting from the large array of BRT elements and integrating them into comprehensive systems.

1.2 BRT IN THE TRANSPORTATION PLANNING PROCESS

Understanding BRT's capabilities is important for assessing its performance and potential benefits during an Alternatives Analysis. The Federal Transit Act requires that all requests for capital assistance for New Start funds be preceded by an alternatives analysis where a full range of feasible, potentially cost-effective alternatives for addressing specific transportation needs are objectively and transparently evaluated. Despite the fact that BRT is a *bona fide* rapid transit concept, local planning efforts often do not have complete information regarding BRT's:

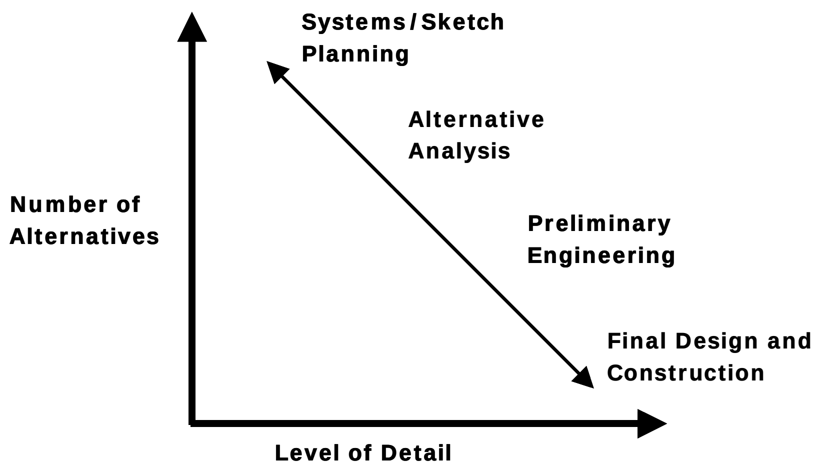
- Physical and operating characteristics
- ridership attraction
- capital, operating and maintenance costs
- performance in terms of speed, reliability and other measures
- air, noise, and other environmental impacts
- ability to induce sustainable, transit oriented land uses

Unfamiliarity with these characteristics of BRT affects the ability of planning to support completely informed decision making about investments.

In addition to the need for better information about BRT for use in Alternatives Analyses, there is also a need for information on BRT for less complex, "first cut" sketch planning exercises, where an initial list of viable, potentially desirable alternatives is developed. Exhibit 1-1 illustrates the relationship of the number of alternatives considered during Systems / sketch planning, Alternatives Analysis, Preliminary Engineering and other planning and project development steps to the level of design detail utilized.

Early in the planning process, there are many alternatives available to solve a specific transportation need. Because of resource constraints, all alternatives cannot be exhaustively analyzed in detail at all planning stages. Once the universe of potentially feasible options have been narrowed down to a small number through the sketch planning process, a more detailed analysis can be undertaken. Initially, sketch planning techniques are used to establish the range of alternatives that meet screening criteria, ruling out those alternatives determined to have "fatal flaws" or with significantly lower performance than others. In essence, it sets the agenda for subsequent and more detailed Alternatives Analyses.

Exhibit 1-1: Transit Investment Planning and Project Development Process



Although sketch planning does not provide the level of detail necessary in the Alternatives Analysis process, it does require planners to grasp the universe of potential alternatives, and have access to accurate and balanced information about the ability of each alternative to meet a broad set of performance, operational and cost objectives.

After a detailed Alternatives Analysis in support of major investment decision-making is performed (e.g., to support a subsequent FTA New Starts funding application), only one recommended alternative defined in terms of mode, systems concept and general alignment will remain. At this stage, the project can advance to preliminary engineering, which uses much more detailed engineering and operations analysis, provides a complete description of the given alternative. Preliminary engineering is followed by final design and construction.

1.3 INTENDED USE OF THE CBRT REPORT

The purpose of the CBRT report is to provide a useful reference for transit and transportation planning officials involved in sketch planning and detailed Alternatives Analyses. The report provides a detailed overview of BRT's six basic elements, and the costs and benefits of combining them in different ways. CBRT provides information useful to planners who serve decision-making on each element and on how the elements might be packaged into an integrated system to produce the maximum benefits.

The data provided in this report can also be used to assess the reasonableness of cost estimates and ridership forecasts prepared as part of FTA Alternative Analyses through detailed engineering studies, ridership traffic and cost modeling. While the report does not contain the data needed to develop operating and maintenance cost models, it does provide information that can be used as a "baseline" to assess the reasonableness of forecasts produced from these requirements. In cases where more detailed alternatives development and analysis is needed before decision makers can reach closure, the CBRT report provides practitioners with benchmark data to assess the reasonability and reliability of the benefits, costs and impact assessment results produced by more detailed analysis tools such as travel forecasting, multi-modal traffic simulation and fully allocated or incremental operating and maintenance cost models.

Exhibit 1-2 below summarizes the potential applications of the CBRT report in the planning and project development process described above. Of the three major steps described in Exhbit 1-2 – Systems Planning, Alternatives Analysis, and Preliminary Engineering – the CBRT is most relevant to the first two, Systems Planning and Alternatives Analysis.

Note that the emphasis of the CBRT report is on front-end transit planning and development, where analytical detail is not as critical to decision-making as having conceptual mastery of viable project alternatives. At the beginning of the planning process, the CBRT report helps senior planners and decision-makers identify the range of possibilities at both the individual element and systems level as quickly as possible.

It also provides aggregate physical, operational, cost and performance information useful in reducing the number to a more manageable sub-set for subsequent analysis or implementation, depending on the situation. For more detailed implementation guidance for later and more detailed phases of project design, transportation planners and BRT system designers are encouraged to use the relevant industry standards and codes and the many implementation guidelines that have been developed to support BRT and the bus industry, such as:

- ***TCRP Report 90: BRT Implementation Guidelines***, TRB
- ***Transit Capacity and Quality of Service Manual***, TRB

- ***Highway Capacity Manual***, TRB
- ***Standard Bus Procurement Guidelines***, APTA
- ***ITS Enhanced Bus Rapid Transit***. FTA, June 2003
- ***BRT Vehicle Characteristics***. FTA, April 2001

In addition, products of TCRP Project A-23A, ***Costs and Effectiveness of Selected Bus Rapid Transit Components***, which is to be completed in 2005, is expected to produce research that thoroughly explores the impacts of specific Bus Rapid Transit components and to catalog costs and effectiveness of bus rapid transit systems.

Exhibit 1-2: Characteristics of BRT in Project Planning and Development

Planning / Project Development Phase	**Bus Corridor Improvements, Package < $25M**	**Small Starts, <$75M**	**New Starts, >$75M**
Screening Of Alternatives / Systems Planning / Sketch Planning	*Process Function: Identification And Screening Of Broadly Defined System Package Concepts For Refinement And Analysis*		
	Criteria: Sketch Planning Level Of Detail Cost, Benefit And Impact Estimates		
	Products: Alternatives For Further Refinement And/Or Analysis		
Alternatives Analysis	N/A	*Process Functions: Less Detailed Analysis; Fewer "Justification" Criteria Needed; Otherwise Same As For New Starts*	*Process Functions: Definition Of Alternatives At Both BRT Element And System's Package Level; Check Reasonability Of Analysis Results*
		Criteria; More Accurate Estimates Of Costs, Benefits And Impacts For System Alternatives	*Criteria: More Accurate Estimates Of Costs, Benefits And Impacts For System Alternatives*
		Outcome: Single System's Package To Bring Into Project Development/PE	*Outcome: Single System's Package To Bring Into Project Development/PE*
Preliminary Engineering	Process Functions: Detailed Definition Of Each Element In Selected System Package; Assessment Of Reasonability Of Specifications And Cost Estimates, By Element		
	Criteria: Detailed Cost, Performance And Impact Estimates To Take Into Final Design And Implementation		
	Outcome: Detailed Definition Of Project To Take Into Final Design/Implementation		

1.4 STRUCTURE AND CONTENT OF CBRT

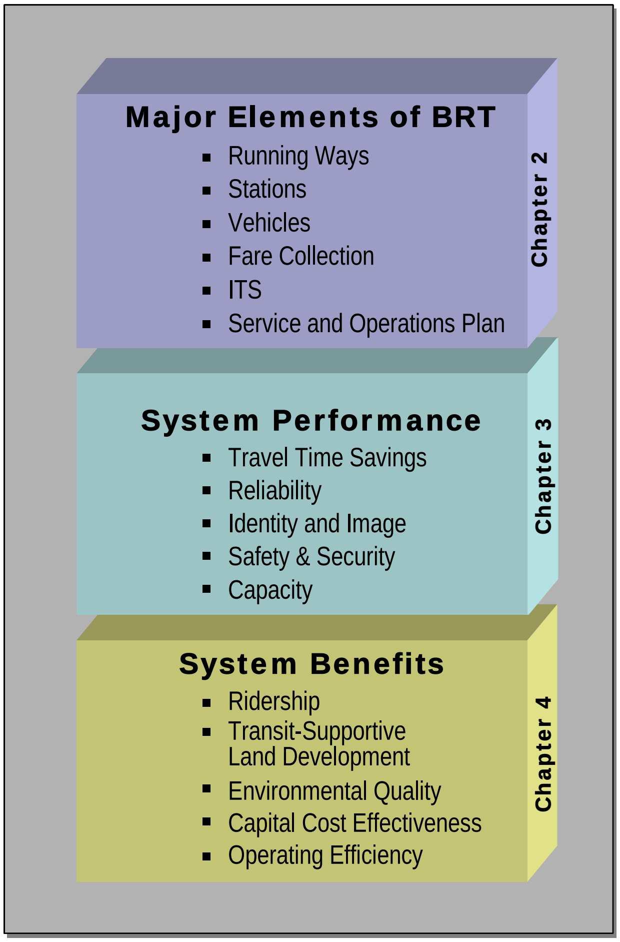
The core of the CBRT report is organized into three related topic areas, as illustrated by Exhibit 1-3:

- Major Elements of BRT (Chapter 2) – this chapter describes six major BRT elements, including detailed discussion of the options and associated costs for each— Running Ways, Stations, Vehicles, Fare Collection, Intelligent Transportation Systems, and Service Plans. A discussion on integrating these elements and developing a branding scheme around them completes the chapter.

- BRT Elements and System Performance (Chapter 3) – this chapter discusses how each BRT element contributes to transit objectives including reducing travel times, improving reliability, providing identity and a quality image, improving safety and security, and increasing capacity.

- BRT System Benefits (Chapter 4) – this chapter describes some of the most important benefits of integrated BRT systems in terms of ridership, economic development, and environmental mitigation. The chapter also includes an assessment of the impact of BRT system implementation on two important categories of transit system performance — capital cost effectiveness and operating efficiency.

Exhibit 1-3: Characteristics of Bus Rapid Transit for Decision-Making (CBRT) Report



The three-part conceptual framework describes the function of each element as a part of an integrated package, and identifies the functional interface between related elements in achieving specific performance objectives. For example, the effectiveness of certain elements is either magnified or nullified when implemented in combination with other elements. Functional interface issues like these will be carefully identified in Chapters 2 and 3.

Accordingly, information on performance measures and outcomes (e.g., capacity, operating and maintenance costs, revenue speeds, ridership) will be included at the systems as well as individual element levels.

The remainder of the report synthesizes the information presented in Chapters 2, 3, and 4 and presents findings and conclusions.

- Chapter 5 concludes with a summary of BRT experience. It provides a summary of how elements have been implemented, on what performance objectives have been achieved and what benefits are generated. Chapter 5 also describes how the CBRT report will be sustained as a vital source of information on BRT.

- Appendices include a glossary of terms related to BRT, summaries of the BRT projects BRT system details and specifications, and illustrations of applications of BRT elements.

2.0 MAJOR ELEMENTS OF BRT

As described in Chapter 1, Bus Rapid Transit is a flexible, permanently integrated package of rapid transit elements with a quality image and distinct identity. This chapter describes the characteristics, range of options, and (where possible) capital and operating costs and a variety of other critical planning parameters for the following six major BRT elements.

- **Running Ways** - Running ways drive travel speeds, reliability and identity. Options range from general traffic lanes to fully-grade separated BRT transitways.
- **Stations** – Stations, as the entry point to the system, are the single most important customer interface, affecting accessibility, reliability, comfort, safety, and security, as well as dwell times, and system image. BRT station options vary from simple stops with basic shelters to complex intermodal terminals with many amenities.
- **Vehicles** - BRT systems can utilize a wide range of vehicles, from standard buses to specialized vehicles. Options vary in terms of size, propulsion system, design, internal configuration, and horizontal/longitudinal control, all of which impact system performance, capacity and service quality. Aesthetics, both internal and external are also important for establishing and reinforcing the brand identity of the system.
- **Fare Collection** – Fare collection affects customer convenience and accessibility, as well as dwell times, service reliability and passenger security. Options range from traditional pay-on-board methods to pre-payment with electronic fare media (e.g., smart cards).
- **Intelligent Transportation Systems (ITS)** – A wide variety of ITS technologies can be integrated into BRT systems to improve BRT system performance in terms of travel times, reliability, convenience, operational efficiency, safety and security. ITS options include vehicle priority, operations and maintenance management, operator communications, real-time passenger information, and safety and security systems.
- **Service and Operations Plan** – Designing a service plan that meets the needs of the population and employment centers in the area and matches the demand for service is a key step in defining a BRT system. How it is designed can impact system capacity, service reliability, and travel times, including wait and transfer times.

The aim of this chapter is to describe the discrete options available for each BRT element. Greater detail on the performance of these elements as part of comprehensive systems and in terms of how they relate to specific BRT objectives will be presented in Chapter 3.

In the next six sub-sections, Sections 2.1 through 2.6, each element will be discussed according to the following structure:

- Description – A brief description of each element with:
  - Role of the Element – A description of the role of each element in BRT systems
  - Element Characteristics – A discussion of the primary characteristics of each element
- Options – Various options for each element characteristic will be presented with images and costs.
- Implementation Issues – A set of issues will be presented for each element
- Summary of Experience – Real-world information on implementation of the element in BRT systems.

Since each of these six elements must be combined in an integrated fashion to maximize the impact of the investment, the last section, Section 2.7, explores how BRT can be integrated into a package, particularly with respect to two issues:

- Branding – Elements need to be combined to support the brand identity and the overall public appeal of BRT services to potential riders.
- Interfaces – Particular elements have design interfaces with other elements.

2.1 RUNNING WAY

2.1.1 Description

Role of the Running Way in BRT

Just as rail transit vehicles travel down tracks, bus rapid transit vehicles travel on guideways or running ways. In fact, how running ways are incorporated into a BRT system is the major defining factor of a BRT system. Running ways are the most critical element in determining the speed and reliability of BRT services. Running ways are also often the most significant cost item in the entire BRT system. Finally, as the BRT element visible to the largest number of potential and existing customers, running ways can have a significant impact on the image and identity of the system.

Characteristics of Running Way

There are three primary BRT running way characteristics:

- **Degree of Segregation** – The level of separation from other traffic is the primary running way planning parameter. An existing mixed flow lane on an arterial represents the most basic form of running way. BRT vehicles can operate with no separation from other vehicle traffic on virtually any arterial street or highway. Increasing levels of segregation through exclusive arterial lanes, grade separated lanes or exclusive transitways on separate rights-of-way add increasing levels of travel time savings and reliability improvement for the operation of BRT services. Fully grade-separated, segregated BRT transitways have the highest cost and highest level of speed, safety and reliability of any BRT running way type.

- **Running Way Marking** – Just as a track indicates where a train travels for rail transit passengers and the community, treatments or markings to differentiate a running way can effectively convey where a BRT service operates. Differentiation in the appearance of the running way can be accommodated through a number of techniques including pavement markings, lane delineators, alternate pavement texture, alternate pavement color, and separate rights-of-way.

- **Guidance (Lateral)** – BRT running ways can incorporate a feature known as lateral guidance. This feature controls the side-to-side movement of vehicles along the running way similar to how a track defines where a train operates. Like most bus operations, many BRT systems operate with no lateral guidance, relying on the skills of the vehicle operator to steer the vehicle. Some BRT systems incorporate a form of vehicle guidance to meet one or more of a variety of objectives, including to reduce right of way requirements, to provide a smoother ride and to facilitate “precision docking” at stations, allowing no-step boarding and alighting. Depending upon the type of technology used, the guidance can be mechanical, electro-magnetic, or optical.

2.1.2 Running Way Options

Running Way Segregation

With little or no investment in running ways, BRT vehicles operate in mixed flow lanes in an arterial roadway. Increasing investment in separating BRT vehicles from general traffic brings increasing benefits of speed and reliability. There are four major options for running ways that represent increasing levels of segregation.

Running Way Segregation Types

Mixed Flow Lanes

Unimproved Mixed Flow Lanes

Mixed flow lanes are the most basic form of BRT running way. In fact, most rubber-tired urban transit service operates on mixed flow lanes. BRT vehicles face delays due to conflicts with other vehicles, which also operate within the street.

Los Angeles Metro Rapid

Mixed Flow Lanes with Queue Jumpers

Mixed flow lanes can be augmented through the use of queue jumpers. A queue jumper is typically a short section of roadway on an approach to a bottleneck, (e.g., an intersection), designated for exclusive use of a BRT vehicle or for BRT vehicles and turning vehicles only. A queue jumper thus allows BRT vehicles to "jump the queue" or bypass congestion or delays at intersections. In most applications, queue jumper lanes are used in conjunction with signal priority to allow vehicles to enter an intersection with a special signal ahead of other vehicles.

Cost: Use of existing lanes has minimal costs since there are no modifications to be made.

$0.1 - $0.29 million per queue jump lane section per intersection (excluding ROW acquisition). Costs can be less if existing roadway space can be rededicated for the purposes of queue jump lanes.

Designated (Reserved) Arterial Lanes

In corridors where the alignment of the BRT route follows an existing arterial roadway, designated lanes can provide BRT vehicles with a fast, reliable alternative to mixed flow traffic lanes. With a designated arterial lane, a traffic lane within an arterial roadway is set aside for the operation of BRT vehicles. Other vehicles are restricted from using the lane. This is enforced through a physical barrier or through police enforcement. BRT vehicles thus face minimal congestion delay between intersections. With designated lanes, BRT vehicles are not delayed in the approach to a station by a queue of other vehicles. Designated lanes thus reduce travel times and improve reliability.

Boston Silver Line Phase I

In some cases, specified classes of vehicles are allowed to share the designated lane such as turning vehicles or high-occupancy vehicles. In these cases, slight performance reductions are experienced as a result of delays caused by the movements of automobiles into and out of the running way.

Cost: $2.5 - $2.9 million per lane mile (excluding ROW acquisition)

Running Way Segregation Types

At-Grade Transitways

Standard Lane – Some urban corridors have new or existing rights-of-way available for the construction of infrastructure for exclusive use of transit vehicles. Exclusive facilities offer significant potential for speed, reliability and safety improvements since they physically separate BRT vehicles from the general stream of traffic, eliminating the potential for general traffic to encroach on the BRT lanes. Because other traffic cannot interfere with BRT vehicles, service can be operated safely at much higher speeds between BRT stations. At-grade exclusive lanes do, however, interact with other traffic at cross streets.

Bi-Directional Lane – In certain cases, right-of-way for exclusive lanes may only be wide enough to accommodate one single bi-directional lane. At low frequencies of service, single bi-directional exclusive lanes can provide many of the same benefits as two exclusive lanes. At higher frequencies, sophisticated signal systems and coordinated schedules may be required to ensure safe and unimpeded operation of BRT vehicles.

Cost (not including ROW): $6.5 – 10.2 million per lane mile


East Busway, Pittsburgh

COST ($ Million)

Fully Grade-Separated Exclusive Transitways

The running way type with the greatest level of separation is the grade-separated exclusive transitway. These facilities can either be stand-alone (as in the use of former railroad rights-of-way) or be on a major highway (either running along the side or in the median of a freeway or in a separate elevated or underground viaduct). Grade-separated exclusive transitways allow BRT vehicles to operate unimpeded at maximum safe speeds between BRT stations. Separated from congestion in local streets at intersections and adjacent highways, grade-separated exclusive lanes provide the highest travel time savings, the most reliable travel times and highest degree of safety. For this reason, these types of exclusive lanes typically offer the greatest benefits but at the greatest cost.

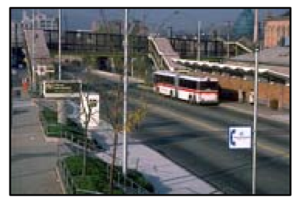
Where volumes of buses is high and where there is a mix of standard and express services, multiple lanes may be necessary to add capacity and to allow passing.

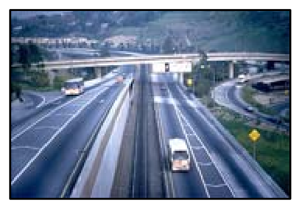
Cost (not including ROW):

Aerial Transitway – $12-30 million per lane mile

Below-grade Transitway -- $60 – 105 million per lane mile

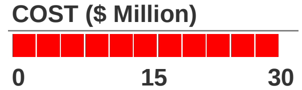
Additional Lanes: $2.5 – 3 million per lane mile (within existing roadway profile); $6.5 – 10.12 per additional lane mile


East Busway, Pittsburgh


El Monte Busway, Los Angeles


East Busway, Pittsburgh

COST ($ Million)



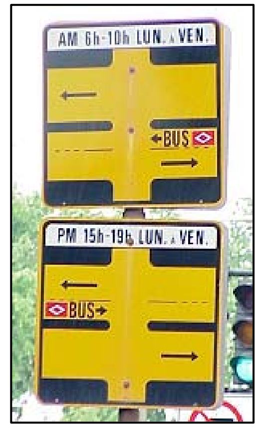
Running Way Marking

Differentiation of running ways can be accomplished through a number of means. The three major techniques are described below.

Running Way Marking

Signage and Striping

Signage is the most basic form of marking a lane as reserved for BRT service. It often includes the use of “diamond” lane symbols to restrict automobile service from the lanes. Where transitways and/or bus lanes are built on arterials, signs are provided in each direction at each intersection



Reversible Lane, Pie IX R-bus, Montreal, Canada

Raised Lane Delineators

Delineators such as raised pavement marking such as colored line, raised curbs, bollards, or bumps in pavement can highlight the distinction between general purpose lanes and BRT running way lanes.


Optibus Lanes, Leon de Guanajuato, Mexico

Alternate Pavement Color / Texture

Implementing alternate pavement color through colored asphalt or concrete can reinforce the notion that a particular lane is reserved for another use, thereby reducing conflicts with other vehicles.


Key Routes, Nagoya, Japan

Guidance (Lateral)

There are three major types of guidance systems – each requiring investment in vehicles and running ways. Guidance systems can be implemented flexibly either all throughout the running way or at specified locations such as narrow sections of right-of-way, tight curves, or approaching and leaving stations.

Running Way Guidance Types

Optical Guidance

Optical guidance systems involve special optical sensors on the vehicles that read a marker placed on the pavement to delineate path of the vehicle. In this guidance option, the only running way requirement is to have large double striped lines in the center of the respective lanes. Complex electronic/mechanical systems are required for each vehicle

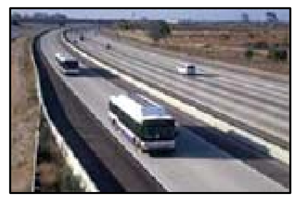
Cost: $11,500 – 134,000 per vehicle

Rouen, France

Las Vegas Regional Transportation Commission is implementing optical guidance for the North Las Vegas Boulevard Corridor at a cost of $95,000 per vehicle.

Electromagnetic Guidance

Electromagnetic guidance involves the placement of electric or magnetic markers in the pavement such as an electro-magnetic induction wire or permanent magnets in the pavement. Sensors in the vehicle read these markers to direct the path of the vehicle. This type of guidance requires significant advanced planning in order to embed the markers under the pavement.



COST ELEMENT	CAPITAL
Magnetic Sensors per Mile	$20,000
Hardware and Integration per Vehicle	$50,000 - $95,000

Mechanical Guidance

Mechanical guidance requires the highest running way investment of all guidance options, but the lowest requirement for complex vehicle systems. Vehicles are guided by a physical connection from the running way to the vehicle steering mechanism, such as a steel wheel on the vehicle following a center rail, a rubber guide wheel following a raised curb, or the normal vehicle front wheels following a specifically profiled gutter next to station platforms.

O-Bahn, Adelaide Australia

2.1.3 Effects of Running Way Elements on System Performance and System Benefits

Exhibit 2-1 summarizes the links between the running way elements to the BRT system performance and system benefits identified in Chapter 1. These links are explored further in Chapters 3 and 4.

Exhibit 2-1: Summary of Effects of Running Way Elements on System Performance and System Benefits

	System Performance					
	Travel Time Savings	**Reliability**	**Identity and Image**	**Safety and Security**	**Capacity**	**System Benefits**
Running Way Segregation Types ▪ Mixed Flow Lanes with Queue Jumpers ▪ Designated (Reversed) Arterial Lanes ▪ At-Grade Exclusive Lane (Transitway) ▪ Grade-Separated Exclusive Lane (Transitway)	▪ Congestion delays decrease with increased running way segregation	▪ Running way segregation reduces the risk of delay due to non-recurring congestion and accidents	▪ Running way segregation highlights a permanent investment and the special treatment for BRT	▪ Separation of BRT vehicles from other traffic streams reduces hazards	▪ Multiple lanes increase capacity ▪ Segregation reduces congestion delay, increasing throughput	▪ Running way segregation highlights a permanent investment that attracts development ▪ Speed benefits associated with running way enhance ridership gain, environmental benefit
Running Way Marking ▪ Signage ▪ Lane Delineators ▪ Alternate Pavement Color/Texture			▪ Markings highlight that BRT running ways are a special reserved treatment			
Running Way Guidance Type ▪ Optical Guidance ▪ Electromagnetic Guidance ▪ Mechanical Guidance	▪ Guidance allow operators to operate vehicles safely at maximum speeds		▪ Guidance provides a smoother ride, enhancing image	▪ Guidance allows for safer operation at higher speeds		

2.1.4 Planning and Implementation Issues

Availability of Right-of-Way – The most significant issue in planning BRT running ways is the availability of right-of-way, whether on an arterial, adjacent to a highway, or on a separate right-of-way. Dedicating space on existing roadways for either queue jumpers at congested intersections or an entire dedicated lane may require reallocation of roadway space from general travel lanes or parking. Given the potential community impacts, changes to the roadway structure needs to be planned carefully.

Enforcement – Managing conflicts with other types of traffic is important to maintain the integrity of any BRT running way. Other vehicles crossing into the path of BRT vehicles or creating congestion in BRT lanes can introduce delays and create safety problems. Enforcing BRT running ways can be done passively through design (e.g., by physical barriers) or active police enforcement. Both types of enforcement require the participation of partners who implement highway design standards and police agencies.

Enforcement strategies must also accommodate the operating of vehicles from other transit agencies and from emergency services such as police, ambulance, and fire services.

Dependability for Optimal Performance – The physical configuration of the running way system and the materials used affects the ability to operate, maintain, and repair it. Certain running way treatments (e.g., optical, gutter profile guidance) may present operations issues in different operating conditions. For example, running ways must accommodate snow removal in northern climates. As another example, the durability of optical guidance markings on the pavement may be affected by dust and heat.

2.1.5 Experience with BRT Running Ways

Most BRT applications in the United States have utilized simple running way treatments – combinations of mixed flow operation with signal priority and dedicated arterial lanes. Exhibit 2-2 presents a summary of BRT running way experience. Use of running way guidance is rare except for a limited application with Las Vegas MAX with precision docking (through optical guidance) at stations. Use of running way markings to differentiate BRT running ways is almost non-existent, showing that a sensibility to incorporating running way design into branding strategies have yet to develop.

Exhibit 2-2: Experience with BRT Running Ways

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Express	City Express	North Las Vegas MAX	Metro Rapid
Running Way Segregation					
Total System Route Miles	2.4 miles	36.7 miles	56.6 miles	7.6 miles	115.3 miles
System Route Length in Mixed Flow Lanes	0.2 miles	36.7 miles	56.6 miles	2.9 miles	115.3 miles
System Route Miles in Designated (Reserved) Arterial Lanes	2.2 miles			4.7 miles	-
System Route Miles in At-Grade Exclusive Lanes				-	-
System Route Miles in Grade-Separated Exclusive Lanes				-	-
Guidance Options (Optical / Mechanical / Electromagnetic / -)	None	None	None	Optical	None
Type of Grade Crossing Treatments	Traffic Signals	Traffic Signals	Traffic Signals	Traffic Signals	Traffic Signals
Running Way Marking	Striping	N/A	Concrete barriers on highway lane	Striping	N/A
Pavement Type (Asphalt / Concrete)	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt with Concrete Pads

Exhibit 2-2: Experience with BRT Running Ways (Continued)

	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	South Dade Busway	Rapid San Pablo Corridor	Lymmo	West Busway	Rapid
Running Way Segregation					
Total System Route Miles	8 miles	14 miles	3 miles	18.4 miles	75.3 miles
System Route Length in Mixed Flow Lanes		14 miles		0.8 mile	31.5 miles
System Route Miles in Designated (Reserved) Arterial Lanes					43.8 miles
System Route Miles in At-Grade Exclusive Lanes	8 miles		3 miles		
System Route Miles in Grade-Separated Exclusive Lanes				17.6 miles	
Guidance Options (Optical / Mechanical / Electromagnetic / -)	None	None	None	None	
Type of Grade Crossing Treatments	Traffic Signals	Traffic Signals	Traffic Signals	Signal Priority (magnetic loop sensors)	Traffic Signals
Running Way Marking	Separate ROW	N/A	Concrete Pavers		Signage
Pavement Type (Asphalt / Concrete)		Asphalt	Concrete Pavers	Asphalt	Asphalt

2.2 STATIONS

2.2.1 Description

Role of Stations in BRT

Stations form the critical link between the BRT system, its customers, and other public transit services offered in the region. They also are locations where the brand identity that distinguishes the BRT system from other public transit services, portraying a premium-type service, while integrating with and enhancing the local environment.

Because BRT systems serve high demand corridors and have only a limited number of stops, the number of customers using each BRT station will be significantly higher than would be the case for a typical local bus line. Accordingly, BRT stations are much more significant than a sign on a pole as is typically the case for conventional local transit bus services. They range from simple stops with well-lit basic shelters to complex intermodal terminals with amenities such as real time passenger information, newspaper kiosks, coffee bars, parking, pass/ticket sales and level boarding.

Characteristics of Stations

Stations have five primary characteristics:

- **Basic Station Type** – There are several major BRT station types, in increasing size and complexity: simple stop, enhanced stop, designated station, and intermodal transit center. BRT stations can be designed to convey a brand identity that distinguishes the BRT system from other public transit services, portraying a premium-type service, while integrating with the local environment.

- **Platform Height –** Platform height affects the ability of disabled or mobility-impaired passengers to board the vehicle. Passengers traditionally board vehicles by stepping from a low curb up to the first step on the vehicle, then climbing additional steps. Given the trend toward widespread adoption of low-floor vehicles, boarding has become easier for all passengers. Platforms at the same height as vehicle floors can enhance customer experience and reduce dwell times if some approach to providing no-gap, no-step boarding and alighting is adopted through provision of drop ramps or precision vehicle docking.

- **Platform Layout** – Platform layout, which describes the length and extent of berthing assignment, also is a major element of station design. It affects how many vehicles can simultaneously serve a station and how passengers must position themselves along a platform to board a given service.

- **Passing Capability** – When service on a running way is so dense that vehicles operate in quick succession, the ability of vehicles to pass each other can maximize speed and reduce delay, especially at stations. Passing capability can be accommodated through a number of means including multiple lanes, passing lanes at stations or intersections, or ability to use adjacent lanes with mixed flow traffic.

- **Station Access –** Station access describes how the BRT system is linked to surrounding communities. Station access can be entirely focused on pedestrian access to adjacent land uses or can emphasize regional access through the provision of large parking garages and lots. The type of parking facility and the number of spaces should be tied to the nature of the market that the station serves and the adjacent physical environment. The provision of parking at the appropriate BRT stations can save overall travel time for customers arriving by automobile from outside the station area and can expand the reach of the system.

2.2.2 Station Options

Basic Station Type

There are four basic BRT station types:

Basic Station Types

Simple Stop

This is the simplest form of the four BRT station types listed within this section. It consists of a "basic" transit stop with a simple shelter (often purchased "off the shelf") to protect waiting passengers from the weather. In general, this type of station has the lowest capital cost and provides the lowest level of passenger amenities.

Cost: $15,000 to $20,000 per shelter. (Only includes cost of the shelter, does not include cost of platform or soft-costs)

San Pablo Rapid Bus Shelter

COST

0 5 10

Enhanced Stop

Enhanced BRT stations include enhanced shelters, which are often specially designed for BRT to differentiate it from other transit stations and to provide additional features such as more weather protection and lighting. This BRT station type often incorporates additional design treatments such as walls made of glass or other transparent material, high quality material finishes, and passenger amenities such as benches, trash cans, or pay phones.

Cost: $25,000 to $35,000 per shelter. (Only includes cost of the shelter, does not include cost of platform or soft-costs)

Los Angeles Metro Rapid Shelter

COST

0 5 10

Basic Station Types

Designated Station

The designated BRT station may include level passenger boarding and alighting, a grade separated connection from one platform to another and a full range of passenger amenities including retail service and a complete array of passenger information.

Cost: $150,000 to $2.5 million per station (lower cost stations include cost of canopy, platform, station enclosure and pedestrian access; higher cost stations designed for higher ridership and include longer platforms and canopies, larger station structure, passenger amenities and roadway access; parking facility costs are not included nor are soft-costs)

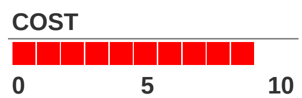
Brisbane South East Busway Station

Intermodal Terminal or Transit Center

The intermodal terminal or transit center is the most complex and costly of the BRT stations listed in this section. This type of BRT facility will often have level boarding, provides a host of amenities, and accommodates the transfers from BRT service to local bus, other public transit modes, e.g., rail transit, and even intercity bus and rail.

Cost: $5 million to $20 million per facility or higher. (Includes the cost of platforms, canopies, large station structure, passenger amenities, pedestrian access, auto access and transit mode for all transit modes served. Does not include soft-costs).

Ottawa Transitway Intermodal Station



Platform Height

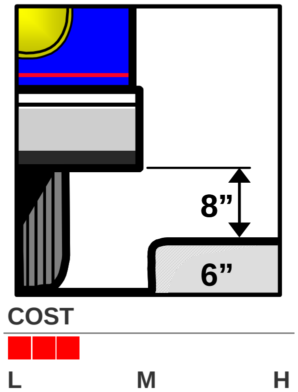
There are three basic platform height options

Platform Heights

Standard Curb

The standard curb causes a vertical gap between the height of the station platform or the curb and the vehicle entry step or floor. This causes customers to step up to enter the BRT vehicle and step down to exit the BRT vehicle. In most instances, this type of platform treatment is used when the station right-of-way cannot be altered.

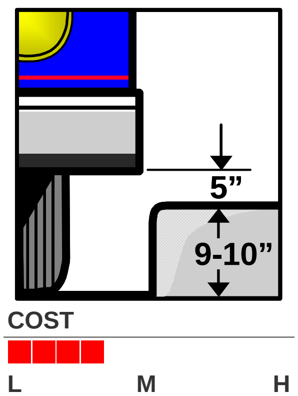
Cost: No incremental cost for station platform



Raised Curb

A raised curb reduces the vertical gap between the platform and the vehicle floor. The raised curb platform height should be no more than 10 inches above the height of the BRT running way or arterial street on which the BRT system operates. In some cases, the raised curb will more closely match the height of BRT vehicle's entry step or floor to accommodate "near" level boarding. This treatment is preferred over the standard curb.

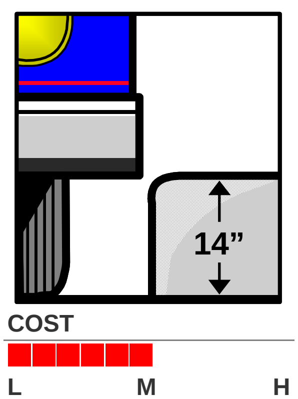
Cost: No significant incremental cost, requires an additional 3-4 inches of concrete depth



Level Platform

To create the safest, easiest, and efficient manner of customer boarding and alighting, platforms level with BRT vehicle floors (approximately 14 inches above the pavement for low floor vehicles) are the preferred station platform treatment. Level station platform boarding and alighting platforms enhances the customers traveling experience by creating a seamless transition between station and vehicle.

Cost: No significant incremental cost, requires an additional 8 inches of concrete depth



Platform Layout

Platform layouts range from single vehicle length with a single berth (boarding position), usually from 60 feet where only conventional 40 foot buses are used, to as long as 300 or more feet where multiple articulated buses must be accommodated:

Platform Layouts

Single Vehicle Length Platform

This is the shortest platform length necessary for the entry and exit of one BRT vehicle at a time at a station.

Boston Silver Line Phase I

Extended Platform with Un-Assigned Berths

Extended platforms usually accommodate no less than two vehicles and allow multiple vehicles to simultaneously to load and unload passengers. Since this platform can accommodate more than one vehicle at a time, overlay services can more easily utilize the BRT stations and running way.

Cost: Incremental cost will be a multiple of a single vehicle length platform based on the maximum number of vehicles accommodated

Vancouver 98-B Line Station

COST

L M H

Extended Platform with Assigned Berths

Extended platforms with assigned berths have all of the features of extended platforms but also assign vehicles serving specific routes to specific positions on the platform. This is the longest of the two platform length options.

Cost: Incremental cost will be a multiple of a single vehicle length platform based on the maximum number of vehicles accommodated

Miami South Busway
Dadeland South Station

COST

L M H

Passing Capability

The ability for BRT vehicles in service to pass one another at stations is important in two primary cases:

- In mixed flow operation, where frequency is high and travel times are highly variable
- In cases where multiple types of routes (local and express) operate along the same running way and serve uneven levels of demand

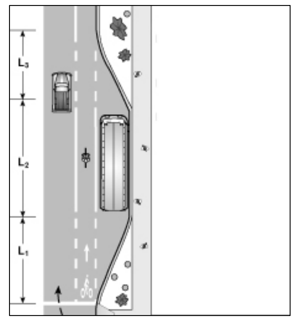
In both of these cases, BRT vehicles can delay other BRT vehicles operating on the same running way if there is no ability to pass one another at stations.

Passing Capability Options

Bus Pull-outs

For both arterial BRT operation and exclusive lanes, bus pull-outs at stations allow buses serving a station to pull out of the BRT running way and, thus out of the way of BRT vehicles that need to pass vehicles stopped at the stations.

Cost: $0.05 million – 0.06 million per pull-out (per station platform)



Passing Lanes at Stations

Passing lanes at stations allow a vehicle in express services to pass through a station at full speed or a vehicle to overtake stopped.

Cost: $2.5 - $2.9 million per lane mile (excluding ROW acquisition)

Ottawa Transitway

Station Access

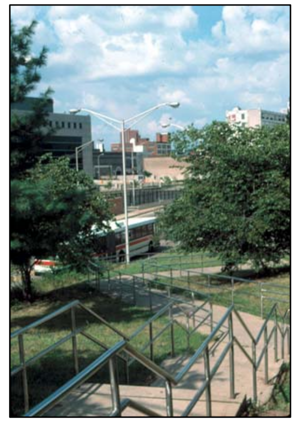
Transit systems require linkages to adjacent communities in order to draw passengers from their market area – either through pedestrian linkages to adjacent sites or connections through the roadway network to adjacent neighborhoods by automobile or non-motorized modes.

Station Access Options

Pedestrian Linkages

Pedestrian linkages, such as sidewalks, overpasses and pedestrian paths are important to establish physical connections from BRT stations to adjacent sites, buildings, and activity centers.

Cost: Typically included in the base cost for Designated Stations and Intermodal Terminas or Transit Centers



Walkway to Station, Port Authority of Allegheny County

COST

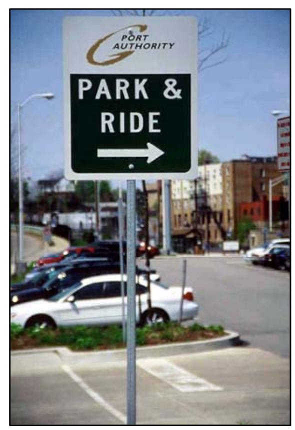
L M H

Park-and-Ride Facility

Park-and-ride lots allow stations, especially those without significant development, to attract passengers from a wide area around BRT stations.

Because services can be routed off the primary running way, regional park-and-ride facilities can also be located off the running way. This arrangement can link BRT service with existing parking lots, potentially reducing capital investment costs.

Cost: $3,500 - $5,000 for a surface space $10,000 to $25,000 per space for structured space



Park-and-Ride Lot, Port Authority of Allegheny County

COST

L M H

2.2.3 Effects of Station Elements on System Performance and System Benefits

Exhibit 2-3 summarizes the links between the station elements to the BRT system performance and system benefits identified in Chapter 1. These links are explored further in Chapters 3 and 4.

Exhibit 2-3: Summary of Effects of Station Elements on System Performance and System Benefits

	System Performance					
	Travel Time Savings	**Reliability**	**Identity and Image**	**Safety and Security**	**Capacity**	**System Benefits**
Station Types ▪ Basic Shelter ▪ Enhanced Shelter ▪ Designated Station ▪ Intermodal Transit Center	▪ Integrated stations serving multiple services minimize transfer time penalties		▪ More distinct station types enhance the brand identity of the system ▪ Additional amenities appeal to customers	▪ More defined stations build in design treatments to link to surrounding communities	▪ Larger stations increase loading capacity at stations	▪ More defined stations attract potential development
Platform Height • Standard Curb • Raised Curb • Level Platform	▪ Reduced vertical clearance facilitates boarding and reduces dwell time	▪ Reduced vertical clearance facilitates boarding and reduces dwell time variability	▪ Level platforms present an image of advanced technology, similar to some rail systems	▪ Reduced vertical clearance may reduce tripping during boarding and alighting	▪ Reduced dwell times for platform heights increase station throughput	
Platform Layout ▪ Single Vehicle Length Platform ▪ Extended Platform with Un-Assigned Berths ▪ Extended Platform with Assigned Berths	▪ Allowing multiple vehicles to load and unload facilitates lower station clearance time	▪ Allowing multiple vehicles to load and unload reduces delay			▪ Longer platforms limit queuing delays for vehicles waiting to load	
Passing Capability ▪ Bus Pull-outs ▪ Passing Lanes at Stations	▪ Passing at stations allows for express routes and minimizes delays at stations	▪ Passing at stations allows for schedule maintenance and recovery			▪ Passing limits queuing delays at stations	
Station Access ▪ Pedestrian Linkages ▪ Park-and-Ride Facility			▪ Treatments to highlight station access provide attract riders	▪ Better pedestrian linkages to communities facilitate integration with communities		▪ Better access attracts customers

2.2.4 Implementation Issues

The flexible and diverse nature of BRT presents unique issues and challenges related to station implementation

Availability of Property – Just as the availability of right-of-way is an issue in the implementation of running ways, the availability of physical property for stations is a key factor in station planning. BRT lines using curb lanes or that operate in mixed traffic along arterials typically serve stations sited on existing sidewalks. Clearance for pedestrian and wheelchair traffic must be accounted for in the design of stations on public sidewalks. In some cases, additional street right-of-way is required either through partial lane realignment or a sidewalk extension (a “bulb out”). Planners must balance the needs of parking, general traffic lanes, and BRT stations. Finally, in exclusive running way sections, additional real estate is required to build full stations. In some cases, station platforms must fall on opposite sides of the street due to right-of-way constraints.

Pedestrian / Patron Access and Safety – Care must be taken to minimize the conflict between pedestrians and BRT vehicles in and around stations. The need to develop a strong linkage for pedestrians and wheelchairs to adjacent communities will affect the site layout for BRT stations. Because station platforms typically are not significantly higher than the running way through the station, there is a risk of pedestrians walking into the path of an oncoming BRT vehicle to cross from one platform to another. Similar conflicts between pedestrians and BRT vehicles may occur at crossings between the BRT running ways and cross streets. Some BRT designs incorporate elements that minimize this conflict. For example, the Southeast Busway in Brisbane, Australia provides overhead walks to access/egress stations for increased customer safety. The overhead walks were also provided as a result of physical station location space limitations.

Security – Station plans should account for the possibility of crime or other security threats. Common ways of deterring crime include a high level of general lighting, surveillance cameras and equipment, emergency call boxes, closed-circuit television monitoring, extensive spot illumination, and the use of transparent materials (e.g. glass) and be designed in a way that preserves sight lines. Passive ways of incorporating security into the design focus on openness, high visibility and intense lighting. Unobstructed sight lines enable BRT customers to view their surroundings and be viewed within and outside of the facility.

Community Integration – As the primary starting point for a transit journey, stations provide the first impression of the transit system and are the primary link between the system and its surrounding community. Station design and pedestrian linkages to the surrounding community are critical in conveying an identity for the BRT system. Two key considerations are important to consider in designing stations to integrate with the community:

- Landscaping and Public Art – BRT system integration into an urban setting provides an opportunity to beautify the areas around running ways and stations with landscaping and other upgraded amenities such as lighting, sidewalks, street furniture, and public art including statues and other art objects.
- Planning and Zoning – Planning guidelines and zoning regulations define the intensity and character of the existing and potential development around a station. It is

important, therefore to account for planning and zoning in order to make sure that the station design is integrated well with current and future development.

Advertising – Transit agencies often incorporate advertising to earn additional revenue. The station design, therefore, may need to incorporate provisions for print or electronic advertising that balance the agency's revenue generation goals with the aesthetic requirements of the BRT system and the surrounding communities.

2.2.5 Experience with BRT Stations

Most BRT applications in the United States use a combination of simple to enhanced station and stop designs and treatments. Designated stations and intermodal stations are used primarily with exclusive transitways. Route maps and schedule information, seating and trash containers are among the most common amenities incorporated at stations. BRT systems with more complex stations, such as Pittsburgh, include more amenities such as heating, public address systems, and emergency telephones. Pittsburgh's Busways and Las Vegas MAX are the only United States BRT systems that incorporate raised curbs or level boarding, respectively. Most BRT systems, with the exception of Orlando, have some provision for passing at stations, either through the use of adjacent mixed flow lanes or passing lanes at stations. A summary of United States BRT systems is presented in Exhibit 2-4.

Exhibit 2-4: Experience with BRT Stations

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Express	City Express	North Las Vegas MAX	Metro Rapid
Station Type					
Total Number of Stations in System		77	135		173
On-Street Shelter (Number of Stations in System)				-	-
Enhanced Shelter (Number of Stations in System)				-	X
Designated Station (Number of Stations in System)				20 (10 per direction)	-
Intermodal Transit Center (Number of Stations in System)				-	-
Amenities at Typical Stations					
Telephone	-	-	-	-	-
Restroom	-	-	-	-	-
Vending	-	-	-	Beverages	-
Seating	-	-	X	X	-
Trash Container	X	-		X	X
Temperature Control	-	-	-	-	-
Public Art	-	-	-	-	-
Public Address	-	-	-	-	-
Emergency Telephone	X	-	-	-	-
Security Monitoring (CCTV / Police Presence)	-	-		-	-
Platform Height (Standard Curb / Raised Curb / Level Platform)	Standard Curb	Standard Curb	Standard Curb	Level Platform	Standard Curb
Maximum Vehicles Accommodated	1	1	1	1	1
Length					
Passing Capability (Adjacent Mixed Flow Lane / Bus Pullouts / Passing Lanes / No Passing)	Adjacent Mixed Flow Lane		Adjacent Mixed Flow Lane	Bus Pullouts	Adjacent Mixed Flow Lane
Parking Facility Options (Number of Stations with Park-and-Ride Lots)					0

* Where two platforms serve different directions of travel is counted as one station.

Exhibit 2-4: Experience with BRT Stations (Continued)

	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	South Dade Busway	Rapid San Pablo Corridor	Lymmo	Busways	Rapid
Station Type					
Total Number of Stations in System	23		11	25	138
On-Street Shelter (X/-) (Number of Stations in System)			11		46
Enhanced Shelter (X/-) (Number of Stations in System)	23	X	-		46
Designated Station (X/-) (Number of Stations in System)			-	22	46
Intermodal Transit Center (X/-) (Number of Stations in System)			-	3	
Amenities at Typical Stations					
Telephone (X/-)	X	-	-	-	-
Restroom (X/-)	-	-	-	-	-
Vending (X/-)	-	-	-	-	-
Seating (X/-)	X	X	X	X	X
Trash Container (X/-)	X	X	X	X	-
Temperature Control (X/-)	-	-	-	X	-
Public Art (X/-)	-	-	X	-	-
Public Address (X/-)	-	-	X	X	-
Emergency Telephone (X/-)	X	-	-	X	-
Security Monitoring (CCTV / Police Presence)	-	-	X	-	-
Platform Height (Standard Curb / Raised Curb / Level Platform)	Standard Curb	Standard Curb	Standard Curb	Raised Curb	Standard Curb
Maximum Vehicles Accommodated	2	1	2	3	1
Length	40 to 80 feet				
Passing Capability (Adjacent Mixed Flow Lane / Bus Pullouts / Passing Lanes / No Passing)	Passing Lanes Bus Pullout	Adjacent Mixed Flow Lane	No Passing	Passing Lanes	Passing Lanes Bus Pullout
Parking Facility Options (Number of Stations with Park-and-Ride Lots)	4		1	38	4

2.3 VEHICLES

2.3.1 Description

Role of Vehicles in BRT

Vehicles have a direct impact on speed, capacity, environmental friendliness and comfort. BRT vehicles are also the element of BRT that most passengers and non-customers associate with the BRT system's identity. As the BRT element in which customers spend the most time, passengers derive much of their impression of the BRT system from their experience with vehicles. For non-passengers, vehicles are the system elements that are most visible.

Characteristics of Vehicles

Four primary attributes define BRT vehicles:

- **Vehicle Configuration** – The basic physical configuration of BRT vehicles is a function of the combination of size, floor height, and body type. Transit vehicles in the United States have traditionally been high-floor vehicles with steps. In response to the Americans with Disabilities Act (ADA), low-floor vehicles have become the norm in conventional transit operations. Vehicles in U.S. BRT applications range from low-floor two-axle 40- or 45-foot units to three-axle 60-foot articulated buses.

- **Aesthetic Enhancement** – Aesthetic treatments, including paint schemes and styling options affecting the appearance and configuration of the vehicle body contribute to BRT system identity, positioning it as a quality option and providing information to potential customers as to where to access BRT services. Interior amenities such as high quality interior materials, better lighting and climate control also contribute to the customer perception of comfort and service quality.

- **Passenger Circulation Enhancement** – Several enhancements can be added to vehicles to facilitate circulation onto and off the vehicle and within the vehicle. These include the provision of additional or wider door channels or the provision of doors on the opposite (left) side of the vehicle. Internal circulation enhancements include the provision of alternative seat layouts and alternative wheelchair securement positions.

- **Propulsion** – Propulsion systems determine the acceleration, maximum speed, fuel consumption and emissions characteristics of BRT vehicles. They also affect the noise and smoothness of operation, service reliability and have a large impact on over-all BRT system operating and maintenance costs.

2.3.2 Vehicle Options

Vehicle Configuration

The vehicle configuration is the primary vehicle planning/design parameter for BRT systems. The configuration captures the combination of the length (capacity), body type, and floor height of the vehicle. In practice, BRT systems can use a variety of different vehicle configurations on a single running way. Each configuration can be tailored to a specific service profile and market. Because of the flexibility of vehicle implementation, some communities choose to launch service with 40- to 45-foot vehicles with a plan to transition to 60-foot articulated buses as demand matures.

While local transit services and many BRT systems use high-floor vehicles, low floor vehicles are slowly becoming the predominant choice among transit agencies in the U.S.

Vehicle Configurations

Conventional Standard

Conventional standard vehicles are 40-45 feet in length and have a conventional ("boxy") body. The partial low-floor variety (now the norm among urban transit applications) contains internal floors that are significantly lower (14 inches above pavement) than high floor buses. They typically have at least two doors and a rapidly deployable ramp for wheelchair –bound and other mobility-impaired customers.

Capacity: A typical 40-foot vehicle has seating for 35-44 patrons expanding to between 50 and 60 seated and standing.

A typical 45-foot vehicle can carry 35-52 passengers seated and 60-70, seated and standing, counting stands.

Cost: Typical base price range-$300,000 to $350,000

NABI 40 LFW
Los Angeles Metro

COST

0 0.8 1.6

Stylized Standard

Stylized Standard vehicles have all of the features of a conventional step low-floor vehicle. The major difference is that they incorporate slight body modifications or additions to make the body appear more modern, aerodynamic and attractive.

Capacity: Similar to Conventional Standard vehicles of the same size.

Cost: Typical base price range-$300,000 to $370,000

NABI Compobus 45C-LFW
(Source: Cliff Henke)

COST

0 0.8 1.6

Vehicle Configurations

Conventional Articulated

The longer, articulated vehicles have a higher passenger carrying capacity (50% more) than standard vehicles. Typical floors are partial low floors with steps with two or three doors.

Articulated vehicle seating capacity depends heavily on the number and placement of doors ranging from 31 (four wide doors) to 65 (2 doors) and total capacity of 80-90 passengers, including standees.

Cost: Typical base price-$500,000 to $645,000

New Flyer DE60LF-BRT

NEOPLAN AN460-LF

COST

0 0.8 1.6

Stylized Articulated

Stylized articulated vehicles are emerging in the US to respond to BRT communities' desire for more modern, sleeker and more comfortable vehicles. Step-low floors, at least three doors, with 2 double stream and quick deploy ramps all facilitate boarding and alighting to shorten stop dwell times.

Cost: Typical price range - $ 630,000 to $950,000

NABI 60-BRT

COST

0 0.8 1.6

Specialized BRT Vehicles

Specialized vehicles employ a modern, aerodynamic body that has a look similar to that of rail vehicles. They also employ advanced propulsion systems and often come with advanced ITS and guidance systems.

Cost: Typical price range - $ 950,000 to $1,600,000.

Ciivis by Irisbus operating in Las Vegas

COST

0 0.8 1.6

Aesthetic Enhancement

Above and beyond the basic vehicle type, several aesthetic enhancements can be added to vehicles to enhance the attractiveness of vehicles to passengers. Selection of these features can have important impact on community and rider acceptance.

Aesthetic Enhancements

Specialized Logos and Livery

Specialized logos and vehicle livery are often used to create a specialized identity by establishing a brand and a theme that patrons recognize and associate with the positive attributes for the BRT system. Use of such features to differentiate BRT systems from other services requires a dedicated fleet, which may preclude operations strategies such as interlining and rotating vehicles with local transit service.

Cost: No cost increment.

Larger Windows and Enhanced Lighting

The incorporation of larger windows (especially on low floor vehicles) and interior light fixtures that allow for abundant, flattering light, day or night to provide an “open feeling” can improve the perception and reality of passenger security. Larger windows for each passenger – to see in and out – is important for perceived patron security.

Cost: Normally a part of vehicle base price.

Enhanced Interior Amenity

Enhanced interior amenities such as more comfortable seating, higher quality materials and finishes, better lighting, and climate control can improve the perception of cleanliness, quality construction, and safety.

Cost: Normally included a part of vehicle base price. The increment above basic interior amenities depends upon the particular vehicle order.

Passenger Circulation Enhancement

Several features govern accessibility to BRT vehicles and circulation within vehicles. These features can have important impacts on dwell time, capacity, passenger comfort, and community and rider acceptance.

Passenger Circulation Enhancements

Alternative Seat Layout

Alternative seat layout with seating placed against the sides of the vehicle can increase the aisle width within the vehicle increasing the standing capacity of the vehicle as well as providing additional space for passenger circulation. This layout may also provide intangible benefits such as conveying an impression of openness and accessibility.

Cost: Normally a part of vehicle base price.

Additional Door Channels

Curb side – Additional door channels and wider doors facilitate the boarding process by allowing multiple queues of passengers to enter the BRT vehicle at one time.

Opposite side – Adding doors to the opposite side of the vehicle (the left side in the United States) can allow for access from center platform stations in the median of an arterial. This additional feature improves the flexibility of running ways in which the BRT system can operate and simulates the flexibility of rail systems.

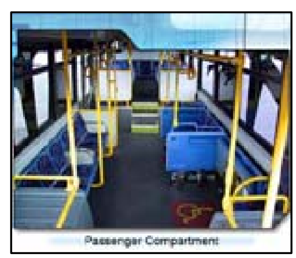
Cost: Not significant for original vehicle orders. Opposite side doors may require additional structural modifications to vehicle orders.

Van Hool

Enhanced Wheelchair Securement

Conventional wheelchair securement involves the use of tie-downs, wheel locks and belts, involving a process that takes between 60 and 200 seconds including boarding time. Alternative wheelchair securement devices are currently being explored to reduce the amount of time to secure wheelchairs in bus operation. In BRT applications, particularly in Europe, rear facing wheel chair positions and no-gap, no-step boarding and alighting eliminate the requirement for lifts, ramps and wheel chair securement. Other types of alternative restraint systems include a 4-point belt tie-down system (kinedyne) and an automated docking system securing the rear of the wheelchair.

Cost: Not yet widely available commercially

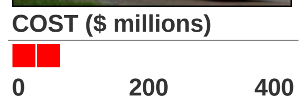


Propulsion System

Spurred on by the evolution of regulations supporting clean air, the number of choices in vehicle propulsion systems is increasing. Technology is evolving to provide new propulsion systems that use cleaner, alternative fuels and new controls on emissions, resulting in reduced pollution and lower noise emissions. Because many new technologies are being introduced and market conditions, such as demand and cost of production, are evolving.

Propulsion Systems

Internal Combustion Engines



The internal combustion engine fueled by ultra low-sulfur diesel (ULSD) or compressed natural gas (CNG) with spark-ignition coupled with an automatic transmission is the most common propulsion system today. Some transit authorities are testing other fuels such as biodiesel, diesel emulsion blends and even LNG but these are a small fraction of transit applications.

The impending EPA requirements on emissions in 2007 and 2010 for NOx and PM will require engines with Exhaust Gas Re-circulation (EGR) plus exhaust after-treatment technology.

Cost: CNG price increment over ULSD is ~$40,000 per vehicle. Infrastructure capital ~ $700,000-$1,000,000

Trolley, Dual Mode and Thermal-Electric Drives

Electric trolley bus drives powered by overhead catenary-delivered power are still produced today and are planned in limited quantities for operation in tunnel BRT applications. Dual mode systems with an on-board thermal engine (usually diesel) can provide a capability to operate as a trolley and as an ICE vehicle off the catenary for specialized operations. Also, a thermal-electric drive, which couples an ICE to a generator, is used as a drive system in vehicles such as Civis by Irisbus being deployed in Las Vegas BRT.

Cost: Cost increment over diesel ICE is $200,000 to $400,000.

Hybrid-Electric Drives

Hybrid-electric drive systems offer improved performance and fuel economy with reduced emissions (e.g., of nitrogen oxides (NOx) and particulates (PM). They differ from dual-mode systems in that they incorporate some type of on-board energy storage device (e.g., batteries or ultra capacitors).

Though the thermal or internal combustion engines used for hybrid drives are diesel in most transit applications, in a number of cases (e.g., Denver 16th Street Mall Vehicles) CNG or gasoline fueled engines have been used. Fuel economy gains of up to 60 % are being claimed in urban service. Operational tests show improved range and reliability over ICE buses. Hybrid buses have entered operation in places such as New York and Seattle.

Hybrid drive offers numerous operational advantages over conventional diesel buses, such as smoother and quicker acceleration, more efficient braking, improved fuel economy and reduced emissions.

Cost: Price increment over diesel ICE is $100,000 to $250,000.

Propulsion Systems

Fuel Cells

A number of operational tests of fuel cell buses are underway this year and next in Europe and the US. Although the price is prohibitive currently, there is great interest in future development to provide zero emissions using domestically produced hydrogen. There are no plans as yet for fuel cell buses in BRT system applications in the United States or Europe.

Currently not commercially available.

2.3.3 Effects of Vehicle Elements on System Performance and System Benefits

Exhibit 2-5 summarizes the links between the vehicle policies, practices, and technologies to the BRT system performance and system benefits identified in Chapter 1. These links are explored further in Chapters 3 and 4.

Exhibit 2-5: Summary of Effects of Vehicle Elements on System Performance and System Benefits

	System Performance					
	Travel Time Savings	Reliability	Identity and Image	Safety and Security	Capacity	System Benefits
Vehicle Configurations ▪ Conventional Standard ▪ Stylized Standard ▪ Conventional Articulated ▪ Stylized Articulated ▪ Specialized BRT Vehicles	▪ Low floors reduce dwell time delays	▪ Low floors reduce variation in dwell time	▪ Advanced vehicles highlight the distinctiveness of BRT and foster linkages to communities	▪ Low floors diminish tripping hazards	▪ Larger vehicles increase capacity	▪ Advanced vehicles attract ridership
Aesthetic Enhancement • Specialized Logos and Livery • Larger Windows and Enhanced Security Treatments • Enhanced Interior Amenity			▪ Treatments to improve the appearance and styling enhance brand identity	▪ Larger windows with other treatments for greater visibility enhance security		▪ Attractive vehicles attract ridership
Passenger Circulation Enhancement ▪ Alternative Seat Layout ▪ Additional Door Channels ▪ Left Side Doors ▪ Enhanced Wheelchair Securement ▪ Interior Bicycle Securement	▪ Improved passenger circulation and disabled access reduce dwell time delays	▪ Improved passenger circulation and disabled access reduce variation in dwell time	▪ Improved access to mobility impaired groups enhances image of service ▪ Left side doors simulate rail systems	▪ Easier disabled securement facilitates safety	▪ Improved passenger circulation increases vehicle throughput of BRT facilities	
Propulsion Systems ▪ Internal combustion Engines ▪ Trolley, Dual Mode and thermal-Electric Drives ▪ Hybrid-Electric Drives ▪ Fuel Cells	▪ Vehicles powered by electricity (trolley, dual-mode, and hybrid-electric drives) have faster acceleration rates from stops.		▪ Low emissions systems enhance the environmental image of BRT			▪ Low emissions systems maximize environmental quality

2.3.4 Implementation Issues

Two major issues need to be considered when implementing vehicles for BRT.

Maintenance Requirements – Maintenance and storage facilities need to be modified or expanded to accommodate BRT vehicles depending on the scope of BRT implementation. The cost impact can be anywhere between a few million to modify an existing facility to $25 million or more to build a new one.

- Maintenance Training – New vehicles may require new maintenance skills and procedures, especially if the BRT vehicle fleet is distinct from other vehicles.

- Facilities Modification and Site Re-Design – Communities planning purchase of 60-foot articulated vehicles will need facility modifications to maintenance buildings and yards if the property is currently using 40-foot vehicles. Typical modifications include extension of inspection pits, installation of three post axle-engaging hoists, modification or relocation of bus maintenance equipment, conversion to drive-through maintenance bays, and reconfiguration of parking and circulation layout of yards.

- New Facility Location – If significant numbers of new vehicles are needed, a new facility location must be identified to accommodate the BRT fleet.

- Fueling – Fueling facilities may also need to be modified to accommodate new vehicles and possibly longer vehicles.

Regulatory Compliance –New vehicle models must pass a variety of regulations in order to be approved for operation:

- The federal **Buy America** provision requires a certain percentage of the vehicle be produced within the United States.

- Safety – Buses must satisfy regulations that govern safe operations of vehicles such as the FTA Bus Testing Program and other safety regulations from the National Highway and Traffic Safety Administration (NHTSA). Some states also place their own standards on vehicle design, including standards on safety and design standards such as maximum length for passenger vehicles. Some state motor vehicle regulations restrict vehicle length to 60 feet in length and 102 inches in width with axle loading of 16,000 lb.

- Pollution control – The EPA and local air quality management districts govern requirements on pollutant emissions. For example, many articulated and bi-articulated large vehicles are only produced in diesel or electric drive. Some local air quality management districts also mandate emissions technologies that vehicle manufacturers currently do not incorporate into the vehicle models they produce.

- Disabled Access – Many aspects of vehicles – boarding interface, interior layout, placement of fare systems, use of ITS, and wheelchair securement – must meet the requirements of the Americans with Disabilities Act (ADA).

2.3.5 Experience with BRT Vehicles

There are at least thirty communities in some stage of planning one or more BRT corridors, plus the nine BRT service implementations that are in operation now listed in Exhibit 2-6. The Exhibit 2-6 highlights the vehicles in use presently for those nine communities. The vehicle configurations range from Conventional Standard in lengths as short as 28' to 61' Specialized BRT articulated vehicles. Six systems use a unique logo and livery to differentiate the service from local transit systems and which provides a distinctive identity that surveyed riders have found to be appealing and useful.

Low floor or step-low floor vehicles are in service in seven of the nine implementations. A mix of standard height and low-floor vehicles are in use in Miami and Pittsburgh. Chicago currently has implemented their service with standard floor buses.

The 28' to 30' buses are single door vehicles but the higher capacity 40' to 60' vehicles have two or three doors for use as entry and exit channels as shown in the Exhibit. The Civis, used in Las Vegas has four doors for use. Both Las Vegas and Oakland have more door channels for a given length of vehicle and less seating, facilitating faster loading and unloading of passengers at stations. Other systems use standard seating configurations and number of door channels.

Choices for propulsion systems reflect both the technology available at the time of vehicle purchase and transit property policy. The internal combustion engine powered by ultra low sulfur diesel or compressed natural gas (CNG) is the predominant choice for reduced emissions. Some transit agencies have sought out and purchased hybrid-electric drive trains for emissions control as well as fuel savings, which has motivated the most recent selection, by Honolulu, of a hybrid power train for their BRT service vehicles.

Exhibit 2-6: Experience with BRT Vehicles

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Express	City Express	MAX	Metro Rapid
Configuration	Stylized Articulated (60')	Conventional Standard (40')	Conventional Articulated (60')	Specialized BRT Vehicle	Conventional Standard (40')
Manufacturer and Model	NEOPLAN USA AN 460 LF		New Flyer DE60LF_BRT	Irisbus Civis	NABI 40LFW
Distinctive Livery	Silver band similar with T logo, similar to rail vehicle livery	--	Rainbow Wrap matched to Shelters	Blue, white and gold	Red and silver fields on Livery, Red / White Metro Rapid Logo
Floor Height	Step Low Floor	High	Step Low Floor	Full Low Floor	Step Low Floor
Number of Doors for Boarding	1	1	1	4	1
Number of Doors for Alighting	3	2	3	4	2
Bus Capacity (Seated)	57			31	39
Bus Capacity (Seated and Standing)	104			120	51
Propulsion System	ICE	ICE	Hybrid	ICE-Electric	ICE
Fuel	CNG	Diesel	ULSD	Diesel	CNG
Interior Features				Alternative seat layout, shape and materials	Luggage Rack over wheel wells
Wheelchair Loading	Front-door Ramp	Lift	Ramp	Level Platforms; Rear door ramp backup	Ramp
Wheelchair Securement Type	Strap	Strap	Strap	Strap	Strap

Exhibit 2-6: Experience with BRT Vehicles (Continued)

	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	South Dade Busway	Rapid	Lymmo	Busways	Rapid
Configuration	Conventional Standard (40')	Stylized Standard (40.5')	Conventional Standard (35')	Conventional Standard and Articulated	Stylized Standard
Manufacturer and Model	30' Optares/40 NABI 40 LFW	Van Hool A330	New Flyer		NABI 40LFW
Description of Livery / Image	--	Red, White and Green Livery	LYMMO Logo	--	Silver Field with Green and Violet RAPID Logo
Floor Height	Step Low Floor	Full Low Floor	Low	High	Step Low Floor
Number of Doors for Boarding	1	1	2	1 (inbound); 2-3 (outbound)	1
Number of Doors for Alighting	2	3	2	2-3 (inbound); 1 (outbound)	2
Bus Capacity (Seated)	28	28	20		41
Bus Capacity (Seated and Standing)	52	77	36 (53 during special events)		63
Propulsion System	ICE	ICE	ICE	ICE	ICE
Fuel	Diesel	ULSD	Diesel	Diesel	LNG
Interior Features			Padded seats, Transit TV	Cushioned Seats	High-back seating, luggage racks, overhead lighting, reclining seats
Wheelchair Loading	Ramps	Ramp	Ramp	Lift	Ramp
Wheelchair Securement Type	Strap	Rear-Facing Position	Strap	Strap	Strap

2.4 FARE COLLECTION

2.4.1 Description

Role of Fare Collection in BRT

Fare collection systems for BRT can be electronic, mechanical, or manual, but the key BRT planning objective is to support efficient, e.g., multiple stream boarding, for what are extremely busy services. Factors include fare policies (e.g., flat fare versus zone or distance), fare collection practices, and payment media. Rather than exhaustively reviewing the large body of literature on fare collection[2], this section focuses on the specific BRT fare collection processes, structures, and technologies. It describes the various fare collection options for BRT systems and provides cost estimates for various electronic fare collection (EFC) approaches.

Characteristics of Fare Collection

The three primary design attributes of a BRT fare collection system are the fare collection process, fare transaction media, and fare structures.

- **Fare Collection Process** - The fare collection process is how the fare is physically paid, processed, and verified. It can influence a number of system characteristics including service times (dwell time and reliability), fare evasion and enforcement procedures, operating costs (labor and maintenance), and capital costs (equipment and media options).

- **Fare Media** - The fare media helps to process transactions associated with a given fare collection process. The choice of fare transaction media includes the instruments associated with the selected equipment, technologies, and fare collection processes. The choice and design of fare media can also influence the service times, auxiliary uses, as well as the capital and operating costs of the fare collection system.

- **Fare Structure** – BRT fare structures greatly influence the choice of fare processes and technologies. As noted, it is influenced by the existing or legacy systems of an organization or region. Transit agencies may consider a number of design factors including their size, network, organization, customer base, as well as financial, political, and management-related variables. The two basic types of fare structures flat fares and differentiated fares.

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[2] *More information on fare collection systems can be found in the following Transit Cooperative Research Program Publications:*
Fare Policies, Structures, and Technologies Update, *TCRP Report 94, 2003;*
"Developing a Recommended Standard for Automated Fare Collection for Transit", TCRP Research Results Digest 57, 2003;
A Toolkit for Self-Service, Barrier-Free Fare Collection, *TCRP Report 80, 2002;*
Multipurpose Transit Payment Media, *TCRP Report 32, 1998;*
"Multipurpose Fare Media: Developments and Issues", TCRP Research Results Digest 16, 1997;
Bus Transit Fare Collection Practices, *TCRP Synthesis of Transit Practice 26, 1997.*

2.4.2 Fare Collection Options

Fare Collection Process

The basic fare payment systems and verification options are listed below with their associated advantages or disadvantages[3]:

Fare Collection Processes

Pay on-board system (i.e., inside or upon entering the vehicle)

Typically involves a farebox or a processing unit for tickets or cards adjacent to the operator. The considerable advantage of this system is that it does not require significant fare collection infrastructure outside the vehicle. Requiring passengers to board through a single front door and pay the fare as they enter, however, will result in significant dwell times on busy BRT routes, particularly those with heavy passenger turn-over. If fares are paid without driver supervision, there is increased risk of fare evasion.

Cost: No incremental cost, assuming this is the current fare collection process. Low to moderate equipment costs. Low to moderate labor costs including, for example, several Full-Time Equivalent (FTE) staff for maintenance, revenues servicing/collector, security, and clerical/data support.

Conductor-validated system

Requires the rider to either pre-pay or buy a ticket on-board from a conductor. However, this system is generally not applicable to BRT systems in the United States because of the high labor costs involved in visually validating all tickets.

Cost: There are additional labor costs involved in visual ticket validation in comparison with other pay on-board and pre-payment systems. As an example, one fare inspector (1 FTE) is needed to validate about 3,300 daily passengers.[4]

Barrier Enforced Fare Payment system (i.e., pay-on-entering and/or exiting a station or loading area)

Involves turnstiles, fare gates, and ticket agents or some combination of all three in an enclosed station area or bus platform. It may involve entry control only or entry and exit control (particularly for distance-based fares).

Cost: $30,000 to $60,000 per Ticket Vending Machine (TVM); $20,000 to $35,000 per Fare Gate. May include additional station hardware/software costs. Estimated additional labor requirements for a small implementation (i.e., 25 TVMs and associated systems) may involve maintenance personnel (1 FTE), revenues servicing/collector (1 FTE), security staff (1 FTE), data procession/clerical staff (1 FTE), and fare media sales staff (2.5 FTE).[5]

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3 Cost ranges per unit are based on information on the costs of fare collection systems contained in Appendix C of*:* **Fare Policies, Structures, and Technologies *(Update)***, TCRP Report *94, 2003. The actual cost associated with implementation of an option depends on specific functionalities/specifications, quantity purchased & specific manufacturer.*

4 ***A Toolkit for Self-Service, Barrier-Free Fare Collection****, TCRP Report 80, Table 2-6*

5 ***A Toolkit for Self-Service, Barrier-Free Fare Collection****, Table 2-6*

Fare Collection Processes

Barrier-Free (self-service) or Proof-of-Payment (POP) system

Requires the rider to carry a valid (usually by time and day) ticket or pass when on the vehicle and is subject to random inspection by roving personnel. It typically requires ticket vending and/or validating machines. The advantage of this less restrictive system is that it supports multiple door boarding and thus lower dwell times. The disadvantage is the increased risk of fare evasion. When implementing proof-of-payment, transit agencies should consider how passenger loads, passenger turnover and how interior layout may affect the ability and ease of inspection on-board vehicles.

Cost: $30,000 to $60,000 per Ticket Vending Machine (TVM); labor costs for roving personnel. May include validator equipment and/or additional station hardware and software costs. Estimated additional labor requirements for a small implementation (i.e., 150 validators and associated systems) may involve maintenance personnel (1 FTE), revenues servicing/collector (1 FTE), security staff (1 FTE), data procession/clerical staff (1 FTE), and fare media sales staff (2.5 FTE).[6]

Issue of potential difficulty of inspection on vehicles

[6] ***A Toolkit for Self-Service, Barrier-Free Fare Collection****, Table 2-6*

Fare Transaction Media

Fare collection policies and processes influence the selection of fare payment media and equipment technology. The fare equipment must be capable of handling the selected fare payment media. Likewise, the selected fare payment media may require certain equipment or technology. In turn, fare collection equipment and media utilized by transit agencies depends on the fare payment options given to passengers. The three primary fare media options include:

Fare Transaction Media

Cash (Coins, Bills, and Tokens) and Paper Media (Tickets, Transfers, and Flash Passes)

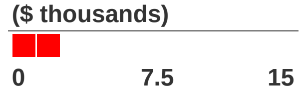
This is simplest but slowest fare media option because of the necessary transaction time, particularly if exact fare is required.

Stored value tickets (the cost of each ride taken being deducted from the stored value) or stored ride tickets (for a single or a given number of rides including booklets with tear-off paper and punch tickets) may require visual verification or manual validation that have an implication on service times depending on the fare collection process.

Period passes (for a specific calendar period, such as a calendar month or week, or special event) or rolling period passes (for a specific number of days after first use, such as day or multi-day tourist passes) usually require visual verification but can be processed faster than cash or tickets.

Cost: No incremental cost, assuming this is the current fare collection process. $2,000 (low cost mechanical farebox) - $5,000 (complex electronic registering farebox)

COST PER VEHICLE ($ thousands)

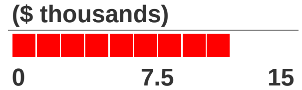


Magnetic Stripe Media.

These cards are made of heavy paper or plastic and have an imprinted magnetic stripe that stores information about its value or use. This type of fare media requires electronic readers, which determine the fare payment time and have implications for dwell times depending on the fare collection process and machinery.

One-Time Cost: $10,000 to $12,000 per validating farebox with magnetic card processing unit ($5,000 to $10,000 more than a standard farebox); $0.01 to $0.30 per magnetic stripe card; $10,000 to $20,000 per garage for hardware/software. May include additional central hardware/software costs.

COST PER VEHICLE ($ thousands)

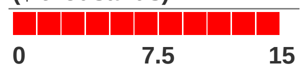


Fare Transaction Media

Smart Cards

Smart Cards generally support faster and more flexible fare collection systems. Contactless or Proximity Smart Cards permit faster processing times than magnetic stripe cards or contact smart cards. They also facilitate processing of differentiated fare structures such as time-based and distance-based fare structures and fare integration across several modes and operators. A hybrid or "dual-interface" smart card can expand the application of smart cards beyond transit.

COST PER VEHICLE ($ thousands)



One-Time Cost: $12,000 to $14,000 per validating farebox with smart card reader ($7,000 to $12,000 more than a standard farebox); $1.50 to $5.00 per smart card; $10,000 to $20,000 per garage for hardware/software. May require expenditure on additional central hardware and software.

Additional costs for different elements of electronic fare collection appear in Exhibit 2-7.

Exhibit 2-6 presents upper and lower estimates of capital and operating costs for various electronic fare collection system elements on a per unit basis or as a percentage of capital equipment expenditures. These ranges are useful for roughly estimating the total cost of a bus EFC system. It is important to note that actual costs will depend heavily on the specifications and functionality, quantity of equipment purchased, and manufacturer of the product. Moreover, in most cases the total cost of an EFC system tends to add (rather than replace or eliminate) previous fare collection costs.[7]

Exhibit 2-7: Estimated Costs for Electronic Fare Systems* (2002 US dollars)[8]

Capital Cost Elements (Bus-Related Fixed Costs per Unit)	Low	High
Mechanical farebox	$ 2,000	$ 3,000
Electronic registering farebox	4,000	5,000
Electronic registering farebox (with smart card reader)	5,000	8,000
Validating farebox (with magnetic card processing unit)	10,000	12,000
Validating farebox (with smart card reader)	12,000	14,000
Validating farebox (with magnetic & smart card reader)	13,000	17,500
Stand-alone smart card processing unit	1,000	7,000
Magnetic farecard processing unit (upgrade)	4,000	6,000
Onboard probe equipment**	500	1,500
Garage probe equipment**	2,500	3,500
Application software (smart card units)	0	100,000
Garage hardware/software	10,000	20,000
Central hardware/software	25,000	75,000
Operation & Maintenance Cost Elements (Variable Costs)	**Low**	**High**
Spare Parts (% of equipment cost)	10%	15%
Support services (% of equip. cost)	10%	15%
(e.g. training, documentation, revenue testing, & warranties)		
Installation (% of equipment cost)	3%	10%
Nonrecurring engineering & software costs (% of equip. cost)	0%	30%
Contingency (% of equipment/operating cost)	10%	15%
Equipment maintenance costs (% of equipment cost)	5%	7%
Software licenses/system support (% of systems/software cost)	15%	20%
Revenue handling costs (% of annual cash revenue)	5%	10%
Clearinghouse*** (% of annual AFC revenue)	3%	6%
(e.g., card distribution, revenue allocation)		
Fare Media Costs per Unit	**Low**	**High**
Magnetic stripe (capacitive) cards	$ 0.01	$ 0.30
Contactless smart cards (plastic)	2.00	5.00
Contactless smart cards (paper)	0.30	1.00

7 *For more information on the costs of fare collection systems, the reader is referred to Appendix C of* **Fare Policies, Structures, and Technologies (Update)**, *TCRP Report 94, 2003.*

8 **Fare Policies, Structures and Technologies: Update (2003)**, *TCRP Report 94, Appendix C*

** Actual cost depends on functionality/specifications, quantity purchased & specific manufacturer.*

*** In an integrated regional system, there is no additional cost for probe equipment.*

**** This depends on the nature of the regional fare program, if any.*

Fare Structure

Transit agencies generally decide on fare collection policies and associated fare system based on a number of factors including their size, network, organization, customer base, as well as financial, political, and management-related goals. There are two basic types of fare structures:

Fare Structures

Flat Fares

Flat fares impose the same fare regardless of distance or quality of service. This policy simplifies the responsibilities of the bus operators by reducing potential confusion and disputes and thus can speed up boarding.

Differentiated fares

Differentiated fares are charged depending on length of trip, time of day, type of customer, speed or quality of service. There are various types of differentiated fare strategies.

- Distance-based or zonal fare is charged as a direct or indirect function of the distance traveled. Bus operators may collect the fare when passengers board or, more rarely, as they exit the vehicle.
- Time-based fares are charged depending on the time of day or length of the trip.
- Service-based fares depend on the type or quality of transit service, which may share stations or infrastructure with other services. Express bus or BRT services may be an example. Generally, this approach is used for multi-modal transit systems and may include transfers.

Other differentiated fare structures include market-based or consumer-based fares, discounted fares, and free-fare zones.

2.4.3 Effects of Fare Collection Elements on System Performance and System Benefits

Exhibit 2-8 summarizes the links between the fare collection policies, practices, and technologies to the BRT system performance and system benefits previously identified in Chapter 1. These links are explored in Chapter 3 and 4.

Exhibit 2-8: Summary of Effects of Fare Collection Elements on System Performance and System Benefits

	System Performance					
	Travel Time Savings	**Reliability**	**Identity and Image**	**Safety and Security**	**Capacity**	**System Benefits**
Fare Collection Process ▪ Pay On-Board ▪ Barrier ▪ Proof-of-Payment	▪ Fare pre-payment can reduce vehicle dwelling and improve overall travel time and reliability	▪ Fare pre-payment can improve dwell time reliability and abnormal delays at stations	▪ Convenience of various fare payment options		▪ Travel time savings and reliability of pre-payment of fares improves system throughput	
Fare Transaction Media ▪ Cash & Paper Only ▪ Magnetic Stripe ▪ Smart Cards	▪ Contactless smart cards or flash passes can reduce transaction times at stations	▪ Contactless smart cards or flash passes can reduce delays due to processing large numbers of passengers at stations	▪ Electronic fare collection enhances convenience, can take advantage of multiple applications / uses, and may propagate image of a premier transit service	▪ Electronic fare collection may limit passenger vulnerability during cash transactions	▪ Travel time savings and reliability of electronic fare payment improves system throughput	▪ Electronic fare collection can reduce the risk of fare evasion and maximize revenue
Fare Structure ▪ Flat ▪ Differentiated	▪ Facilitated transfers can reduce overall travel time and maximize convenience		▪ Differentiated fares may convey image of a higher level of service		▪ Differentiated fares can encourage off-peak usage	▪ Selective discounts to classes of riders or trip types may encourage ridership

2.4.4 Implementation Issues

Integration with Agency-wide Fare Policy and Technology – The choice of fare policy and technologies may depend largely on pre-existing policies or legacy systems. The design of the fare collection system for BRT should consider integration opportunities with other elements of the regional transit system to maximize the potential benefits. These benefits may include any of the objectives previously mentioned, particularly the facilitation of transfers for an enhanced passenger experience.

Revenue Processing – Rapidly evolving technology has led to improvements in revenue processing and control, data collection and storage, and operations monitoring and planning. Electronic Fare Collection systems, using electronic communication, data processing, and data storage techniques to automate fare collection processes, are among these evolving technologies. These systems benefit both transit agencies and passengers.

For transit agencies, EFC systems can represent a reduction in labor-intensive cash handling costs and the risks of internal theft. EFC systems can improve the reliability and maintainability of fareboxes, and permit sophisticated fare pricing structures and automation of financial processes facilitating interactions with multiple operators. For passengers, EFC systems can represent an easier way of traveling since exact change is not necessary and only one fare instrument is needed to use the system. Integrated EFC systems can be used to create multi-modal and multi-provider transportation networks that are "seamless" to the passengers. Some examples of EFC media include magnetic stripe cards, contact smart cards, and proximity smart cards.

Data Collection to Support Planning – The type of data directly or indirectly retrieved from fare collection systems is often used to support planning activities. Therefore, the choice and implementation of fare system options should consider the retrieval and management of useful data. For example, on-board EFC systems may collect information on passenger boardings by location or time of day.

Payment Options and Network - In addition to the fare media discussed, there are several options and other means of purchasing or paying for transit rides:

- Credit cards are utilized in Ticket Vending Machines (TVM) to purchase fare media. They have also been utilized on a limited basis for fare payment on buses.
- Debit or ATM cards are commonly used in TVMs to purchase fare media.
- Transit vouchers to purchase fare media are distributed as part of “transit check” or other employer benefits programs.
- Automatic loading of fare media from pre-established account.

Fare Enforcement – The design aspects of fare collection systems can have an impact on the potential fare evasion and the level of enforcement necessary. Some fare systems may require random inspections or validation. This type of fare enforcement requires an appropriate level of staffing to perform inspections. This additional labor cost may greatly increase operating costs. Fare inspectors may, however, also serve to support the security of the system.

Marketing – Marketing issues include how the fare media are distributed and advertised, incentives to pre-pay fare media, and other features of the fare collection system. These other features can include "negative" balance protection for the customer, a "lowest fare" guarantee, and policies on fare discounts. Electronic fare collection systems also facilitate the implementation of fare promotions.

Fare Media Synergies – It is important to note that more than one type of fare media may be accepted. Fare media may also have multiple applications for auxiliary or complementary services such as:

- Electronic toll collection and parking payments
- Financial services/e-purse payments
- Payphones and mobile commerce
- Other payment and loyalty programs
- Vending machines
- Identification purposes for security and access into buildings

2.4.5 Experience with BRT Fare Collection

As of 2004, BRT systems in the United States are only beginning to offer variations in fare collection as shown in Exhibit 2-9. Most BRT systems use payment on-board the vehicle to a farebox as the primary means to collect fares. The North Las Vegas MAX has inaugurated service with proof-of-payment system. For the Pittsburgh busways, passengers on outbound trips pay on the outbound portion of the trip in order to expedite loading and reduce dwell times in downtown Pittsburgh. Orlando's Lymmo is offered for free and therefore has no delays at boarding or alighting associated with fare collection.

Implementation of electronic fare collection is beginning. The MBTA in Boston has implemented magnetic strip cards on all buses. AC Transit, the Chicago Transit Authority, and the Los Angeles Metro are in various stages of implementing smart cards for fare collection on buses. Only the North Las Vegas MAX has implemented ticket vending machines (TVMs) for BRT as of 2004. TVMs installed can accept cash and magnetic strip tickets to print a proof-of-payment ticket. These TVMs will eventually be outfitted to accept credit card transactions.

Most BRT systems also charge flat fares that are identical to that on the rest of the transit system. Pittsburgh's busways are the only system that charges differentiated fares in the form of distance-based express fares.

Exhibit 2-9: Experience with BRT Fare Collection

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	Silver Line	Express	City Express	North Las Vegas MAX	Metro Rapid	South Dade Busway	Rapid San Pablo Corridor	Lymmo	West Busway	Rapid
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Proof-of-Payment	Pay On-Board	Pay On-Board	Pay On-Board	N/A	Pay on Board	Pay on Board
Fare Transaction Media	Cash, paper, Magnetic stripe card	Cash & Paper, Magnetic Stripe	Cash & Paper	Magnetic Stripe	Cash & Paper, Smart Card (future)	Cash & Paper	Cash & Paper, Smart Card	N/A	Cash & Paper	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Free Fares	Distance – based for Express services	Flat
Equipment at Stations	--	--	--	Ticket Vending Machines [TVMs]	--	--	--	N/A	--	--
Equipment for On-Board Validation	Electronic Farebox	Electronic Farebox	Electronic Farebox	Hand-Held Validators	Electronic Farebox	Electronic Farebox	Electronic Farebox	N/A	Electronic Farebox	Electronic Farebox

2.5 INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

2.5.1 Description

Role of Intelligent Transportation Systems in BRT

Intelligent Transportation Systems (ITS) have helped transit agencies increase safety, operational efficiency and quality of service and may have their highest and best use in BRT systems. ITS includes a variety of advanced technologies to collect, process and disseminate real-time data from vehicle and roadway sensors. The data are transmitted via a dedicated communications network and computing intelligence is used to transform these data into useful information for the operating agency, driver and ultimately the customer. Different combinations of technologies combine to form different types of ITS systems. For example, automatic Vehicle Location (AVL) in combination with Automated Scheduling and Dispatch (ASD) and Transit Signal Priority (TSP) can improve schedule adherence and hence reliability as well as revenue speed.

ITS technologies provide many performance improvements and benefits. The remote monitoring of transit vehicle location and status and passenger activity also improves passenger and facility safety and security. ITS also can be used to assist operators in maintaining vehicle fleets and alert mechanics to impending mechanical problems as well as routine maintenance needs.

ITS applications are fundamental to generating many of BRT's benefits. However, integration of individual ITS applications into the overall BRT system is essential. Combinations of ITS applications must ultimately work together synergistically to provide the high quality service which defines BRT.

Characteristics of ITS

There are many technologies and operational features that can be utilized for BRT systems. Some have been applied by conventional bus systems. In this section, individual ITS technologies that should be considered for integration in BRT systems are discussed, many of which have already provided significant benefits as part of integrated BRT systems. The various ITS applications that can be integrated into BRT systems are discussed below. They have been categorized into seven groups:

- Vehicle Prioritization
- Assist and Automation Technology
- Electronic Fare Collection (Discussed Section 2.4—Fare Collection)
- Operations Management
- Passenger Information
- Safety & Security
- Support Technologies

2.5.2 ITS Options

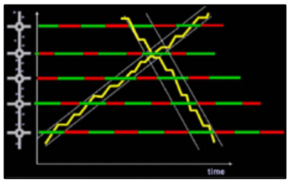
Each ITS group is discussed in the following six sections. Included in each section is an overview of the ITS technologies which includes a description of how the technologies can be utilized and a definition of each technology. Unit costs and actual costs data from transit systems in North America are provided.

Vehicle Prioritization

This technology group includes methods to provide preference or priority to BRT services. The intent is not only to reduce the overall traffic signal delays (thus greater operating speed and shortened travel time) of in-service transit vehicles, but also to achieve greater schedule/headway adherence and consistency (thus enhanced reliability and shorter waiting times). Signal Timing / Phasing and Signal Priority help BRT vehicles minimize delay caused by having to stop for traffic at intersections. Access Control provides the BRT vehicles with unencumbered entrance to and exit from dedicated running ways and/or stations.

Vehicle Prioritization Options

Signal Timing / Phasing



Optimization of traffic signals along a corridor to make better use of available green time capacity by favoring peak, e.g., BRT flows. Requires simulation modeling and analysis using traffic vehicle and person flow data but does not require additional components for the vehicle or infrastructure.

COST ELEMENT	CAPITAL
Signal Retiming per Intersection	$3,500

Station and Lane Access Control

Allow access to dedicated BRT running ways and stations with variable message signs and gate control systems. Requires the installation of barrier control systems that identify a driver and vehicle and/or similar surveillance and monitoring systems. Typically utilizes an electronic transponder (similar to an electronic toll collection system) to allow access while the BRT vehicle is operating at highway speeds.

COST ELEMENT	CAPITAL	O & M
Controller Software for Entire System	$25,000 to $50,000	$2,500 to $5,000
Gate Hardware per Entrance	$100,000 to $150,000	$2,500 to $4,000

Vehicle Prioritization Options

Transit Signal Priority

Traffic Signage – To Deter Autos, Vancouver

Traffic Signal Priority (TSP) technologies can be used to extend or advance green times or allow left turn swaps to allow buses that are behind schedule to get back on schedule, improving schedule adherence, reliability, and speed. Requires traffic signal controllers and software and TSP capable equipment on the transit vehicle and at the intersection for identifying the transit vehicle and generating low priority request when appropriate. It is important to note that although priority and preemption are often used synonymously, they are in fact different processes. While they may utilize similar equipment, transit signal priority modifies the normal signal operation process to better accommodate transit vehicles, while preemption interrupts the normal process for special events or responding emergency vehicles. Objectives of preemption include reducing response time to emergencies, improving safety and stress levels of emergency vehicle personnel, and reducing accidents involving emergency vehicles at intersections. On the other hand, objectives of transit signal priority include reduced travel time, improved schedule adherence, improved transit efficiency, contribution to enhanced transit information, and increased road network efficiency.

COST ELEMENT	CAPITAL
Signal Priority Software	$300 to $600
Signal Controller Hardware	$4,000 to $10,000
Vehicle Hardware	$500 to $2,000

The Chattanooga Area Regional Transportation Authority equipped 27 buses with transit signal priority transmitters, and 10 intersections were equipped with receivers at a total cost of $250,000.

The Los Angeles DOT implemented a bus signal priority system used by Metro Rapid Bus that consists of 331 loop detectors, 210 intersections equipped with automatic vehicle identification sensors at the controller cabinet, 150 transponder-equipped buses, and central control system software at a total cost of $10 million. Loop detection technology is used to detect the presence of a bus approaching the intersection. The bus identification is detected by the AVI sensor and sent to the transit management computer located at the LADOT transportation management center. Average cost: $13,500 per signalized intersection.

The Regional Transportation Commission of Southern Nevada installed a fleet management system to improve transportation efficiency and emergency response performance. This fully integrated, real-time information system is designed for use in the entire fleet, including MAX vehicles. The system features mobile communications, GPS-based automatic vehicle location (AVL), computer-aided dispatch (CAD), two-way messaging, automatic passenger counters (APCs) and a surveillance system.

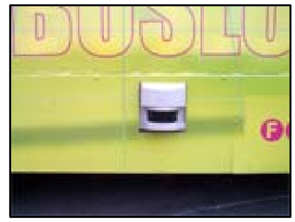
Driver Assist and Automation Technology

This technology group includes technologies that provide automated controls (lateral, i.e., steering and longitudinal, i.e., starting, speed control, stopping) for BRT vehicles. Use of the Collision Warning function assists a driver to operate a BRT vehicle safely. Use of Collision Avoidance, Lane Assist, and Precision Docking functions provides for direct control of the BRT vehicle for collision avoidance, running way guidance, or station docking maneuvers. All assist and automation technologies help to reduce frequency and severity of crashes and collisions and reduced running and station dwell times.

Driver Assist and Automation Technology Options

Collision Avoidance

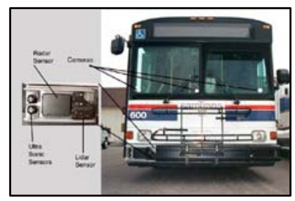
Provision to control the BRT vehicle so that it avoids striking obstacles in or along its path. This includes forward, rear or side impacts or integrated 360 degree system. Requires installation of sensors (infrared, video, or other), driver notification devices, and automated controls within the vehicle. These systems are currently in the research stage and are not available for installation on a BRT vehicle. However, it is expected that over the next five years the BRT vehicle will be used as a platform on which to test these technologies.



Collision Sensor

Collision Warning

Provision of warning for BRT vehicle driver about the presence of obstacles or the impending impact with the pedestrian or obstacle. This includes forward, rear or side impact collision avoidance or integrated 360 degree system. Requires installation of sensors (infrared, video, or other) and driver notification devices within the vehicle. These systems have some limited commercial availability.



COST ELEMENT	CAPITAL
Sensor Integration per Vehicle	$3,500

The Pittsburgh Port Authority (PAT) and Carnegie Mellon University's Robotics Institute have tested a collision avoidance system on 100 buses to warn bus drivers of obstacles in blind spots. The system consists of 12 ultrasonic sensors mounted on the sides of each bus and an on-board computer. Interior warning lights located near the driver's mirrors and an audible indicator are activated if the system determines that the driver needs to take action. Cost: $2,600 (approx.) per vehicle.

Precision Docking

System that assists BRT vehicle drivers to correctly place a vehicle at a stop or station location both latitude and longitude. There are two primary ITS-based methods to implement Precision Docking: magnetic and optical. This requires the installation of markings on the pavement (paint, magnets), vehicle-based sensors to read the markings, and linkages with the vehicle steering system. The availability of these systems is currently limited to international suppliers as an additional option for new vehicle purchases. Commercial availability from US suppliers as an add-on option is expected in the next 2 to 5 years.

COST ELEMENT	CAPITAL
Magnetic Sensors per Station	$4,000
Optical Markings per Station	$4,000
Hardware and Integration per Vehicle	$50,000

Driver Assist and Automation Technology Options

Vehicle Guidance

Guides BRT vehicles on running ways while maintaining speed, using a variety of technologies. These technologies, also known as “lane assist technologies”, allow BRT vehicles to safely operate at higher speeds. There are three primary Vehicle Guidance technologies: magnetic, optical, and GPS-based. They either require the installation of markings on or in the running way pavement (paint, magnets) or development of a GPS-based route map). They also require vehicle-based sensors to read the markings, and linkages with the vehicle steering. The availability of these systems is currently limited. However, commercial deployment is expected within 2 to 5 years.

COST ELEMENT	CAPITAL
Magnetic Sensors per Mile	$20,000
Optical per Mile	$20,000
GPS	$125,000
Hardware and Integration per Vehicle	$50,000 - $95,000

The Las Vegas Regional Transportation Commission implemented a Precision Docking system utilizing the CIVIS vehicle. The technology was a $95,000 option for each of the 10 vehicles.

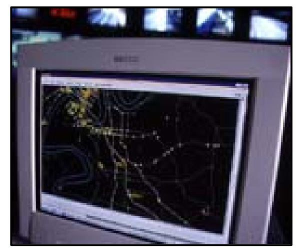
Operations Management Technology

This technology group includes automation methods that enhance management of BRT fleets. Currently, many transit agencies and BRT sites are modifying their existing communication system in order to handle the most basic data needs of AVL systems and Mobile Data Terminals (MDT).

Use of Automated Scheduling Dispatch System and a Vehicle Tracking method assists BRT management to best utilize the BRT vehicles. Use of Vehicle Mechanical Monitoring and Maintenance assists in minimizing downtime of the BRT vehicles. All Operations Management functions improve operating efficiencies, supporting a reliable service and reduced travel times. Solutions that improve BRT performance are described in this section.

Operations Management Options

Automated Scheduling Dispatch System



Utilization of real-time vehicle data (location, schedule adherence, passenger counters) to manage all BRT vehicles in the system and insure proper level of service for passengers. Requires a communication system and vehicle tracking components integrated with an ASDS software package.

COST ELEMENT	CAPITAL	O & M
Hardware and Software Acquisition	$20,000 - $40,000	--
System Integration	$225k - $500k	--

COST ELEMENT	CAPITAL
Sensors and Fleet Integration	$1,100k - $2,200k

Vehicle Mechanical Monitoring and Maintenance

Automatically monitor the condition of transit vehicle engine components via engine sensors and provide warnings of impending (out of tolerance indicators) and actual failures occur. Requires a communication system and on-board mechanical monitoring system that is capable of collecting and transmitting necessary vehicle data.

COST ELEMENT	CAPITAL	O & M
Sensors and Fleet Integration	**$1,100k - $2,200k**	$4,000 - $8,000

Operations Management Options

Vehicle Tracking

Provide transit operations personnel with the current location of BRT vehicles on the network. Transit location information will be used for improved traveler advisory services, schedule adherence and archived to support future planning efforts. Requires a communication system integrated with vehicle tracking components. The most typical installation is based upon the global positioning system (GPS) to identify vehicle location. There are other options which are quickly being replaced.

COST ELEMENT	CAPITAL	O & M
Operations Center Hardware	$15,000 - $30,000	--
Software Integration & Development	$815k - $1,720k	$6,000 to $7,000
Vehicle Hardware	$600 - $1,000	--

The Denver Regional Transportation District installed a GPS-based vehicle location system for approximately 1,000 buses. The installation was part of an overall communication system that consisted of Dispatch Center Hardware ($1,250,000); Radio and Data Computer ($435,000); Field Communication Hardware: $1,451,940; and In-vehicle Hardware at $5,000 per bus.

The Ann Arbor Transportation Authority installed an Advanced Operating System that included vehicle tracking and an advanced communication systems for 75 buses. Capital costs were $2.64 million or approximately $32,500 per bus. O&M cost was estimated at $1.25 million per year (1995 dollars).

Passenger Information

Passenger Information technologies can improve passenger satisfaction, help to reduced wait times, and thus increase ridership. Passenger Information systems can also be a source of revenue through the sale of advertising time and space on information screens. These services rely on a communication system that is able to track individual vehicles, transmit vehicle location data to a central processing center and disseminating processed vehicle data to the transit customer.

For BRT systems, information about the vehicle schedule can be provided to the transit customer at the station / stop and / or on the vehicle. Providing schedule information to travelers via mobile devices (e.g., PDA, cell phone) and supporting trip itinerary planning typically require implementation across the entire transit network.

Note: There are many different cost elements associated with the installation and operation of passenger information system. For the most recent and accurate data, please visit http://www.benefitcost.its.dot.gov. When possible, appropriate system-level data has been provided.

Passenger Information Options

Traveler Information at Stations

Provision of information about vehicle schedule, next bus information or delays within the system via dynamic message sign at the station. Requires techniques to predict the vehicle arrival time and the ability to display this information at the station/stop.

COST ELEMENT	CAPITAL
Transit Information Status Sign	$4,000 - $8,000

The King County Transit Watch system provides transit riders at Bellevue and Northgate Transit Centers in King County, Washington with bus arrival/departure times, bay number, and expected departure times for all bus routes using each of the transfer centers. The Transit Watch system obtained actual departure times from an Automated Vehicle Location (AVL) system, and then presented the information on video monitors at each center. The cost of the system was approximately $723,000 and annual O&M was approximately $180,000.

Passenger Information Options

Traveler Information on Vehicle

Provision of information about next stop, vehicle schedule, transfer/other bus information or delays within the system via dynamic message sign on the vehicle. Requires techniques to predict the vehicle arrival time at the station/stop, receive data on other vehicles along the route and the ability to display this information to transit customers riding on the vehicle.

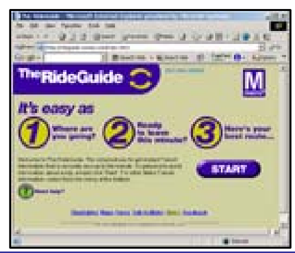
The Transport of Rockland, in New York, installed equipment on three of its 27 buses to automatically announce "next stop" destinations and display on-board route information to assist travelers. The cost to equip each bus was about $7,000. At each bus stop the system automatically announced, in two languages, the location of the next stop and then displayed route destination information on an electronic message sign (2-inch text) located at the front of each bus. On-board global positional systems (GPS) were used to track the location of each bus.

Traveler Information on Person

Provision of information about vehicle schedule, next bus information or delays within the system via PDA, cell phone or similar device used by the traveler. Requires software to provide personal traveler information, and provision of information through the internet or mobile communications (either directly, or through a service provider).

Trip Itinerary Planning

Provision for a traveler to request trip information by specifying a trip origin and destination, time and date. Also provision for a traveler to specify their special equipment or handling requirements.



Safety and Security Technology

Use of Silent Alarms and on-board and in-station Monitoring systems can increase the security of the BRT operation. Specific types of technologies are:

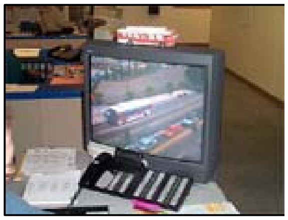
Safety and Security Technologies

Silent Alarms

Alarms installed on the BRT vehicle that are activated by the BRT vehicle driver. A message such has "Call 911" can be displayed on the exterior sign board for others to see or messages can be sent back to the operations center to indicate an emergency or problem.

COST ELEMENT	CAPITAL	O & M
Security Package (Fleet)	$420k - $700k	$21,000 - $26,000

Voice and Video Monitoring



Surveillance of the vehicle, by use of microphone or CCTV camera. Data is sent to an operations center to monitor.

COST ELEMENT	CAPITAL	O & M
Security Package (Fleet)	$420k - $700k	$21,000 - $26,000

In Clearwater and St. Petersburg, Florida, the Pinellas Suncoast Transit Authority (PSTA) installed in-vehicle surveillance systems to help deter crime and prevent false injury claims on buses. Later, the program was expanded to include 16 buses that serve the general public. Each bus was equipped with five video cameras, a microphone, and an on-board computer at a cost of $9,700.

Support Technologies

This ITS group includes a number of support technologies that are required in order in order for ITS to work correctly. Key to the support technologies is the Advanced Communication System which creates a backbone on which the rest of the applications will function. All of these technologies provide no direct impact on performance but are vital to ITS. Each of these technologies are not unique to BRT but do support BRT performance.

Support Technologies

Advanced Communication System

Utilization of the latest in voice and data communication to allow for the operation of other ITS technologies. An ACS is the foundation for many of the ITS technologies. Specific requirements are discussed in section on Implementation Issues: Advanced Communication System.

The Denver Regional Transportation District overall communication system consisted of Dispatch Center Hardware ($1,250,000); Radio and Data Computer ($435,000); Field Communication Hardware: $1,451,940; and In-vehicle Hardware at $5,000 per bus.

The Ann Arbor Transportation Authority installed an Advanced Operating System that included an advanced communication systems for 75 buses. Capital costs were $2.64 million or approximately $32,500 per bus. O&M cost was estimated at $1.25 million per year (1995 dollars).

Archived Data

Store of data that is collected from vehicle sensors (passenger counters, vehicle maintenance systems, etc.) for future planning purposes or analysis.

Passenger Counter

Automatic counting of passengers as they enter and exit the BRT vehicle. Data can be used in real-time for vehicle operations or archived for future planning use. Requires additional sensors for counting passengers either on the vehicle or at the station, and ability to store or transfer the information.

COST ELEMENT	CAPITAL
Automatic Passenger Counting System	$1,000 - $10,000 per Vehicle

The Evaluation of the Advanced Operating System (AOS) of the Ann Arbor Transportation Authority showed that the cost for passenger counting system was approximately $287 per bus, or $21,510 for a 75-vehicle fleet. This represented 0.80% of the total project costs.

2.5.3 Effects of ITS Elements on System Performance and System Benefits

Exhibit 2-10 summarizes the links between the Intelligent Transportation Systems to the BRT system performance and system benefits. These links are explored further in Chapters 3 and 4.

Exhibit 2-10: Summary of Effects of ITS Elements on System Performance and System Benefits

	System Performance					
	Travel Time Savings	**Reliability**	**Identity and Image**	**Safety and Security**	**Capacity**	**System Benefits**
Vehicle Prioritization ▪ Signal Timing/Phasing ▪ Station and Lane Access Control ▪ Transit Signal Priority	▪ Vehicle prioritization minimizes congestion delays	▪ Transit signal priority facilitates schedule recovery	▪ Faster speeds enabled by signal priority enhance image		▪ Vehicle prioritization increases speed and throughput of running ways	▪ Faster speeds attract ridership
Driver Assist and Automation Technology ▪ Collision Avoidance ▪ Collision Warning ▪ Precision Docking ▪ Vehicle Guidance	▪ Precision docking allows for faster approaches to stations and reduced dwell times	▪ Precision docking facilitates boarding and reduces dwell time variability	▪ Precision docking and guidance enhance the image of BRT as advanced	▪ Collision warning and avoidance systems enhance safety ▪ Precision docking	▪ Precision docking limits delays at stations, increasing throughput	▪ Advanced features that enhance BRT system image may attract ridership
Operations Management ▪ Automated Scheduling Dispatch System ▪ Vehicle Mechanical Monitoring and Maintenance ▪ Vehicle Tracking	▪ Active operations management maintains schedules, minimizing wait time	▪ Active operations management focuses on maintaining reliability		▪ Vehicle tracking systems enable monitoring of vehicles ▪ Vehicle health monitoring alerts operators and central control of vehicle malfunction	▪ Operations management ensures that capacity matches demand	▪ Enabling better management of finite resources increases operating efficiencies
Passenger Information ▪ At Station ▪ On Person ▪ On Vehicle ▪ Trip Itinerary Planning	▪ Passenger information systems minimize wait time perceptions	▪ Passenger information allows for notices of service interruption, increasing service reliability	▪ Passenger information systems enhance brand identity and provide a channel to communicate with customers	▪ Passenger information systems allow for communication of security threats		
Safety and Security technology ▪ Silent Alarms ▪ Voice and Video Monitoring				▪ Safety and security systems facilitate active management of the BRT system, deterring crime and enabling responses to incidents		
Support Technologies ▪ Advanced Communication System ▪ Archived Data ▪ Passenger Counter					▪ Support technologies enable operated capacity to be planned to meet demand when needed	▪ Support technologies provide valuable planning information for BRT services

2.5.4 Implementation Issues

While individual ITS technologies provide the basic features key to many of BRT's benefits, the integration of ITS technologies with one another ensure that systems work optimally to maximize the benefit to BRT. The following sections discuss in more detail the implementation issues associated with three of the more important ITS.

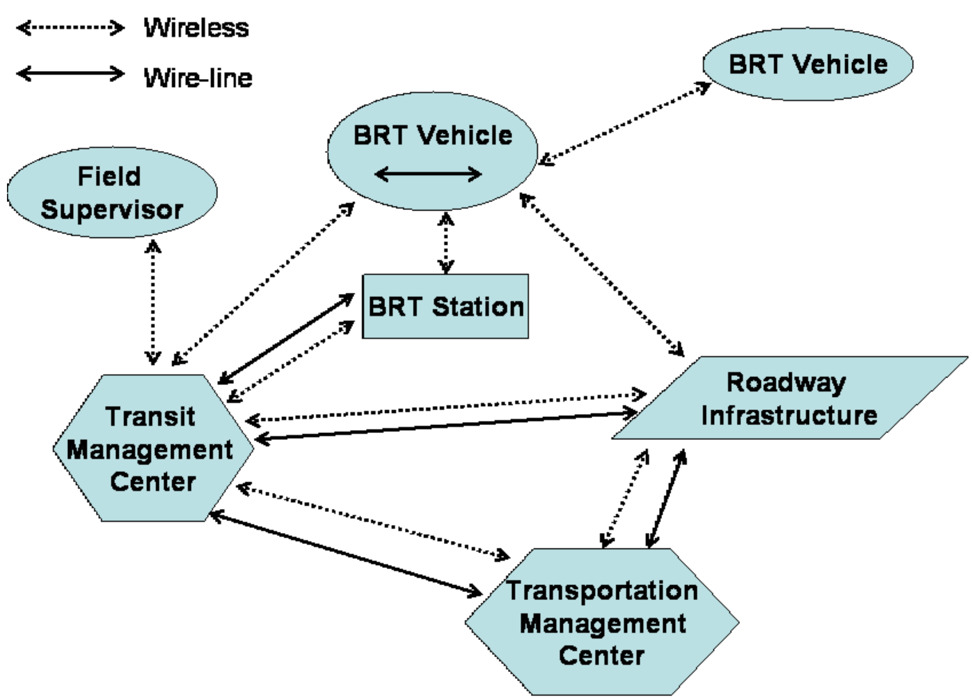
Advanced Communication System

ITS technologies require the utilization of a robust communication system, either via wire-line or wireless, to transmit both voice and data and create an integrated system. Therefore, it is imperative that BRT sites have an Advanced Communication System (ACS) designed to meet the needs of the ITS technologies they plan to deploy and any future technology utilization to have an integrated BRT systems.

BRT operations with signal priority, operator lane assist, reduced headways between vehicles, and real time information may need both more frequent updates and more types of data than normal operations. With the extensive data needs of an ITS-enhanced BRT system, the existing communications systems may very well fall short of providing the necessary bandwidth and speed required for the ITS technologies.

An ACS is not focused purely upon the communications between the BRT vehicle and the transportation management center (TMC). While this is a vital data link, it is just one of the many communication links required for BRT system integration. Exhibit 2-11 provides a schematic of a typical communication system and the interactions between the various elements of BRT system.

Exhibit 2-11: BRT Communication Schematic



An ACS is the foundation of a successfully deployed ITS-enhanced BRT system. All ITS technologies require some form of communication among the BRT vehicle, roadside infrastructure and transit management center. Therefore, in order to have a successfully deployed BRT system, a BRT system must have an ACS that allows for the integration of the various ITS technologies. The ACS essentially provides the means for the synergies of the ITS technologies and BRT concept to come together.

In some instances, a new BRT system will become the impetus for installing a new communication system. For example, the Metro Rapid system in Los Angeles needed some means to transmit data between the BRT vehicle, traffic signal and transit management center in order to implement the TSP system. Because of Metro Rapid, fiber optic cables were installed linking the traffic signals and the TMC. BRT sites will need to analyze communication needs of the planned ITS technologies and compare them to current communication capabilities.

Transit Signal Priority

There are several possible types of traffic signal priority treatments applicable to transit, ranging from the simplest passive priority to the most sophisticated adaptive/real-time control. These TSP strategies vary widely in their benefits and costs, applicability as well as limitations[9].

According to *Advanced Public Transportation Systems Deployment in the United States Year 2000 Update*, there is an 87% increase in the numbers of transit agencies with operational TSP systems from year 1998 (16 agencies) to year 2000 (30 agencies). New and rapid advances in traffic/bus detection and communication technologies, and well-defined priority algorithms have made TSP more appealing or acceptable to more road users of all modes. In fact, TSP appears to be one of the most popular ITS technologies deployed in the BRT environment. Seventeen of twenty-one (81%) BRT sites reportedly are implementing or planning TSP in their BRT systems.

The implementation of TSP cannot be accomplished without full cooperation and coordination from traffic management authorities and all agencies or individuals who will be affected by the project. Most transit agencies have neither jurisdiction nor adequate field operation knowledge over traffic control devices, including signals and signs and pavement markings. TSP also results in impacts on other road users as well as traffic system operations as a whole, such as possible increase in non-transit vehicle delays. All stakeholders need to be involved throughout the project to assure that the system performance outcomes are consistent with project goals and objectives.

Traveler Information

Empirical evidence has demonstrated positive associations between transit ridership and traveler access to transit information. In other words, the more information provided to the

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[9] **An Overview of Transit Signal Priority**, *a recent document published by ITS America, jointly sponsored by the ITS America ATMS and ITS America/APTA APTS committee, provides an introductory overview of TSP related issues.*

traveling public regarding route schedules and arrival information, the greater the acceptance of transit as a viable transportation option[10 11].

Traditionally transit agencies provide traveler information through printed hard copy materials (e.g., riders' guide with route map, fare, and bus schedule) and customer service telephone lines. Recent advances in ITS technologies related to communication and vehicle tracking have afforded transit operators to deliver advanced traveler information to their (potential) customers in a more efficient and effective manner.

When implementing advanced traveler information for BRT, several conditions should be considered. Advanced transit traveler information is delivered to customers through a variety of channels, including, but not limited to: Internet, electronic kiosks, dynamic message signs, video monitors, in-vehicle annunciators, interactive voice response telephone systems, personal digital assistants, and fax. Also, these information channels are making the type of information increasingly dynamic, such as real-time bus arrival/departure status, and incident reporting. In recent years, substantial attention has also been directed to the development of intermodal itinerary/trip planning information systems that are capable of providing seamless, door-to-door trip itinerary planning support to travelers in real time on a request-by-request basis.

2.5.5 Experience with BRT and ITS

Overall, ITS technologies have the potential to improve BRT system performance by leveraging investment in physical infrastrucutre. Among the ten BRT systems presented in Exhibit 2-12, all are either currently using or are planning to use ITS technologies. Implementation of real-time travel information appears to be the most widespread application of ITS. Only five systems have indicated their use of an Advanced Communication System. Implementation of Operations Management technologies such as Advanced Communication Systems, is often tied to systemwide applications.

The implementation of Vehicle Prioritization is mixed for the remaining systems is mixed. The MAX in Las Vegas, Metro Rapid in Los Angeles, and the Rapid Bus in Oakland (AC Transit) have all implemented traffic signal priority. Implementation of transit signal priority is in progress for the Silver Line in Boston for a 2005 system launch.

The implementation of Assist and Automation technologies is rare among current BRT systems. Only the Las Vegas MAX system incorporates one of these technologies – precision docking. There is a significant amount of research and development of Assist and Automation technologies for transit vehicles. BRT vehicles may provide an ideal platform on which to deploy these technologies once they have been proven and are more easily available.

[10] *Abdel-Aty, M. A.,* **"***Using Ordered Probit modeling to Study the Effect of ATIS on Transit Ridership",* ***Pergamon Transportation Research Part C****, 2001, available www.elsevier.com/locate/trc.*

[11] *Syed, S. J. and Khan, A. M***.,** **"***Factor Analysis for the Study of Determinants of Public Transit Ridership",* ***Journal of Public Transportation****, 2000*

Exhibit 2-12: Experience with BRT and ITS

	Boston Silver Line	Chicago Neighborhood Express	Honolulu City Express	Las Vegas MAX	Los Angeles Metro Rapid
Transit Vehicle Prioritization					
Signal Timing/Phasing	-	-	-	-	-
Station and Lane access Control	-	-	-	-	-
Transit Signal Priority (Number of Intersections Applied / Total Number of Intersections)	in late 2004	-	-	12 / 20	676 / 875
Driver Assist and Automation Technology					
Collision Avoidance	-	-	-	-	-
Collision Warning	-	-	-	-	-
Precision Docking Technology	-	-	-	X	-
Vehicle Guidance	-	-	-	Optical	-
Operations Management					
Automated Scheduling Dispatch System	X		X	X	X
Transit Vehicle Mechanical Monitoring & Maint.	-	-	-	-	-
Automatic Vehicle Tracking	GPS	GPS	GPS	GPS	Loop Detectors
Passenger Information					
Traveler Information at Station/Stop	X	-	X	X (Phase 2)	X
Traveler Information on Transit Vehicle	X	-	-	X	X
Traveler Information on/for Person	-	-	-	-	-
Trip Itinerary Planning	X	X	X	X	X
Safety and Security Technology					
Silent Alarms	-	-	-	X	-
Voice and Video Monitoring	-	-	-	X	X
Support Technologies					
Advanced Communication System	X		X	X	X
Archived Data				X	
Passenger Counter		X		X	X

Exhibit 2-12: Implementation of ITS in BRT Systems (Continued)

	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	South Dade Busway	Rapid San Pablo Corridor	Lymmo	Busways	Rapid
Transit Vehicle Prioritization					
Signal Timing/Phasing	-	-	-	-	-
Station and Lane access Control	-	-	-	-	-
Transit Signal Priority (Number of Intersections Applied / Total Number of Intersections)	-		-	1/1	1/1
Driver Assist and Automation Technology					
Collision Avoidance	-	-	-	-	-
Collision Warning	-	-	-	X	X
Precision Docking Technology	-	-	-	-	-
Vehicle Guidance	-	-	-	-	-
Operations Management					
Automated Scheduling Dispatch System	X	-	-		X
Transit Vehicle Mechanical Monitoring & Maint.	X	-	-		
Automatic Vehicle Tracking		GPS	GPS		X
Passenger Information					
Traveler Information at Station/Stop	X	X	X	X	X
Traveler Information on Transit Vehicle	X	-	X	-	X
Traveler Information on/for Person	X	-	X	-	X
Trip Itinerary Planning	-	X	-	X	X
Safety and Security Technology					
Silent Alarms	-	-	X	-	X
Voice and Video Monitoring	-	-	X	-	X
Support Technologies					
Advanced Communication System	-	X	X		X
Archived Data	-		X		X
Passenger Counter	-		X		

2.6 SERVICE AND OPERATING PLANS

2.6.1 Description

Role of the Service and Operating Plan in BRT

The design of the service and operations plan for BRT service affects how a passenger finds value in and perceives the service. BRT service needs to be frequent, direct, easy-to-understand, comfortable, reliable, operationally efficient, and above all, rapid. The flexibility of BRT elements and systems leads to significant flexibility in designing a service plan to respond to the customer base it will serve and the physical and environmental surroundings in which it will operate.

This section details some of the basic service and operational planning issues (certainly not all) related to the provision of BRT service. It should be noted that each of the operational items discussed vary when applied in different corridors, different cities, and different regions depending on a host of factors such as available capital and operating budget, customer demand, available rights-of-way, potential route configuration, and political environment.

Characteristics of the Service and Operating Plan

- **Route Length** - The route length affects what locations a customer can directly reach without transferring as well as determining the resources required for serving the route. Longer routes, while minimizing the need for transfers, require more capital and labor resources and encounter much more variability in operations. Short routes may require passengers to transfer to reach locations not served by the route but can generally provide higher travel time reliability. BRT service need not operate on dedicated facilities for 100% of their length.

- **Route Structure** - An important advantage of BRT running ways and stations is that they can accommodate different vehicles serving different routes. This flexibility allows for the incorporation of different types of routes and route structures with the same physical investment. Managers of BRT systems are thus able to provide point-to-point service or "one-seat rides" to customers thereby reducing overall travel time by limiting the number of transfers. Offering point-to-point service with limited transferring will assist with attracting choice riders to the BRT system.

  There is a trade-off to consider when considering different route structures. Simple route structures with just one or two route patterns are easy for new passengers to understand and, therefore, straightforward to navigate. In order to attract customers, they must be able to easily understand the service being offered. Service directness and linearity in routing are keys to providing customers with a clear understanding of the BRT service. On the other hand, providing additional options, such as through a comprehensive route network with branching routes, gives passengers more choices, especially those passengers who might otherwise transfer. Clarity and choice are two principles that need to be balanced when determining the route structure.

  Different route structures also pose different opportunities for restructuring other transit services. Simple route structures may allow for connecting transit services to be focused on a few stations. Development of branching networks may allow for existing services to be restructured and resources to be reallocated from routes now served by BRT services to other routes.

- **Service Span** – The service span represents the period of time that a service is available for use. Generally, rapid transit service is provided all day with high frequencies through the peak hours that allow passengers to arrive randomly without significant waits. Service frequencies are reduced in off-peak hours such as the mid-day and evening. Service spans affect the segment of the market that a transit service can attract. Long service spans allow patrons with varied schedules and many different types of travel patterns to rely on a particular service. Short service spans limit the market of potential passengers. For example, peak only service spans limit the potential passengers served to commuters with daytime work schedules. Where local and BRT services serve the same corridor, the service span of both local and BRT service may be considered together since passengers may have an option between the two services.

  Exhibit 2-13 describes different BRT service types and typical spans by running way type.

Exhibit 2-13: BRT Service Types and Typical Service Spans[12]

Principal Running Way	Service Pattern	Service		
		Weekdays	Saturday	Sunday
Arterial Streets Mixed Traffic	All Stop	All Day	All Day	All Day
Bus Lanes Median Busways (No Passing)	Connecting Bus Routes	All Day	All Day	All Day
Freeways				
Mixed Traffic	Non Stop with Local Distributor	All Day	All Day	----
Bus/HOV Lanes	Commuter Express	Rush Hours	----	----
Busways	All Stop	All Day	All Day	All Day
	Express	Day Time or Rush Hours	----	----
	Feeder Service	Day Time All Day or Non-Rush Hours	Day Time or All Day	Day Time
	Connecting Bus Routes	All Day	All Day	All Day

12 *Notes:*
All Day - typically 18 to 24 hours
Daytime - typically 7 a.m. to 7 p.m.
Rush Hours - typically from 6:30 to 9 a.m. and 4 to 6 p.m.
1 Feeder Bus Service in Off Peak and Express Service in Peak

Bus Rapid Transit - Implementation Guidelines, *TCRP Report 90-Volume II, 2003.*

- **Service Frequency** - The service frequency directly determines how long passengers must wait for BRT service. Tailoring service frequency to the market served is one of the most important elements in planning and operating a BRT system.

- **Station Spacing** - BRT system operating speeds are greatly influenced by a number of operational planning issues including the distance or spacing between stops. The spacing of stops has a measurable impact on the BRT system's operating speed and customer total travel time. Long station spacing increases operating speeds.

2.6.2 Options in Service and Operations Planning

Route Length Options

Route lengths vary according to the specific service requirements and development characteristics of a corridor. Route lengths of less than 2 hours of total round trip travel time tend to improve schedule adherence and overall system reliability. This generally translates into route lengths a maximum of 20 miles. Keeping total round trip travel time to a minimum is desirable to avoid passengers relying on a printed schedule to use BRT services.

Route Structure Options

There are three types of BRT route structure options for consideration. With each type, higher levels of overlap with the existing transit network may bring increasing opportunity to reallocate service and achieve resource savings.

Route Structure Options

Single Route

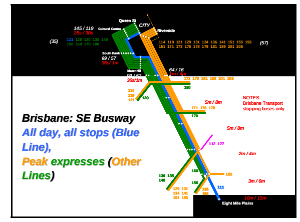
This is the simplest BRT service pattern and offers the advantage of being easiest to understand since only one type of service is available at any given BRT station. This route structure works best in corridors with many activity centers that would attract and generate passengers at stations all along the route.

Overlapping Route with Skip Stop or Express Variations

The overlapping route with skip stop or express variations provides various transit services including the base BRT service. This type of routing offers the advantage of offering express or skip stop service to passengers traveling between particular origin-destination pairs. This route structure works best with passing lanes at stations. Including a high number of routes may cause confusion on platforms for infrequent riders and may cause congestion at stations.

Route Structure Options

Integrated or Network System (with Locals, Expresses, and Combined Line-Haul / Feeders)



The network system route structure provides the most comprehensive array of transit services in addition to the base all-stops, local BRT service. This type of route structure provides the most options to passengers for a one-seat ride but can result in passenger confusion and vehicle congestion pulling into and out of stations.

Span of Service Options

There are two service span options for BRT service:

Span of Service Options

All Day

All day BRT service is usually provided from the start of service in the morning to the end of service later in the evening. This type of service usually maintains consistent headways throughout the entire span of service, even in the off peak periods. Expanding service to weekend periods can reinforce the idea that BRT service is an integral part of the transit network.

Peak Hour Only

This type of BRT span of service option provides only peak hour service. Peak hour only service offers high quality and high capacity BRT service only when it is needed during the peak hours. At other times, the base level of service may be provided by local bus routes.

Frequency of Service Options

The frequency affects the service regularity and the ability of passengers to rely upon the BRT service. High frequencies (e.g., headways of 10 minutes or less) create the impression of dependable service with minimal waits, encouraging passengers to arrive randomly without having to refer to a schedule.

Station Spacing Options

BRT stations are typically spaced farther apart than stops for local service. Spacing stations farther apart concentrates passengers at stations, allowing vehicles to stop and encounter delays at fewer locations along a route. Longer stretch between stations allows vehicles to sustain higher speeds between stations. These factors lead to overall higher travel speeds. These higher speeds help to compensate for the increased amount of time required to walk, take transit, or drive to stations.

Methods of Schedule Control

On-time performance is either monitored to meet specified schedules or to regulate headways. The two methods are described below.

Methods of Schedule Control

Schedule-based Control

Schedule-based control regulates the operation of vehicles to meet specified schedules. Operating policies dictate that operators must arrive within a certain scheduled time at specific locations along the route. Dispatchers monitor vehicle locations for schedule adherence. Schedule-based control facilitates connections with other services when schedules are coordinated to match. Schedule-based control is also used to communicate to passengers that schedules fall at certain regular intervals.

Headway-based Control

Often used on very high frequency systems, headway-based control focuses on maintaining headways, rather than meeting specific schedules. Operators may be encouraged to travel routes with maximum speed and may have no specified time of arrival at the end of the route. Dispatchers monitor vehicle locations and issue directions to speed up or slow down in order to regulate headways and capacity, minimizing wait times and vehicle bunching.

2.6.3 Effects of Service and Operations Plan Elements on System Performance and System Benefits

Exhibit 2-14 summarizes the links between the Service and Operations Plans, policies, practices, and technologies to the BRT system performance and system benefits previously identified. These links are explored in Chapter 3 and 4.

Exhibit 2-14: Summary of Effects of Service and Operations Plan Elements on System Performance and System Benefits

	System Performance					System Benefits
	Travel Time Savings	Reliability	Identity and Image	Safety and Security	Capacity	
Route Length		▪ Shorter route lengths may promote greater control of reliability				▪ Service plans that are customer - responsive attract ridership and maximize system benefits
Route Structure ▪ Single Route ▪ Overlapping Route with Skip Stop or Express Variations ▪ Integrated or Network System	▪ Integrated route structures reduce the need for transfers		▪ Distinctions between BRT and other service may better define brand identity. ▪ Integrated routes structures may widen exposure to the brand.			
Span of Service ▪ Peak Hour Only ▪ All Day		▪ Wide spans of service suggest the service is dependable				
Frequency of Service	▪ More frequent services reduce waiting time	▪ High frequencies limit the impact of service interruptions		▪ High frequencies increase potential conflicts with other vehicles and pedestrians ▪ High frequencies reduce security vulnerability at stations	▪ Operated capacity increases with frequency	
Station Spacing ▪ Narrow Station Spacing ▪ Wide Station Spacing	▪ Less frequent station spacing reduces travel time	▪ Less frequent station spacing limit variation in dwell time				
Method of Schedule Control ▪ Schedule-based Control ▪ Headway-based Control	▪ Headway-based control for high frequency operations maximize speeds					

2.6.4 Experience with BRT Service Plans

In general, the structure of the routes correlated with the level of investment in the running way infrastructure. Projects implemented in at-grade arterial lanes, either in mixed flow or designated lanes were implemented either as a single BRT route replacing an existing local route or as a single BRT route following the same route as a local route. Boston's Silver Line project was the only project where a BRT service totally replaced a local route. The station spacing remained relatively low at one station spaced every 0.22 directional route mile. Most other arterial BRT systems (AC Transit's Rapid Bus, Las Vegas RTC's MAX, Los Angeles Metro's Metro Rapid) involved an overlay of the BRT route over the local route. Station spacing for the BRT route was highest at generally between 0.5 and 1.0 miles. Projects involving exclusive lanes (Miami-Dade's at-grade South Busway and Pittsburgh's grade-separated transitways) operated with integrated networks of routes. In these cases, one route functioned as the base service while other routes combined local feeder operation off the transitway and express operation on the exclusive transitways.

Frequencies also correlated with the running way investments. BRT systems on arterials operated with headways between 9 and 15, with Boston and Los Angeles operating shorter headways in some corridors. Pittsburgh's exclusive running ways demonstrated a combined headway of approximately 1 minute along the trunk transitway.

Except for Phoenix, where the Rapid service operates as a peak-hour only commute service, all BRT systems operated during the same service span and all days of the week as the rest of each transit system.

Exhibit 2-15: Experience with BRT Service Plans

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Neighborhood Express	City Express!	MAX	Metro Rapid
Route Structure (Single BRT Route / Overlapping BRT Routes / Network of BRT Routes)	BRT Route replaced Local Route	BRT Route Overlay onto Local Route	BRT Route Overlay onto Local Route	BRT Route Overlay onto Local Route	BRT Route Overlay onto Local Route
Number of Routes Operating in Network	1	3	3	1	9
Number of All-stop Routes	1	3	3	1	9
Number of Express Routes	-	-	-	-	-
Span of Service (Peak Hour Only / All Day)	All Day	All Day	All Day	All Day	All Day
Frequency of Service (Headway during Peak Hour in Minutes)	4	9 to 12	11	12	2 to 30
Station Spacing (Average Station Spacing in Miles)	0.22	0.47 to 0.56	0.2	0.84	0.67 to 1.17

Exhibit 2-15: Experience with BRT Service Plans (Continued)

	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	South Dade Busway	Rapid San Pablo Corridor	Lymmo	Busways	Rapid
Route Structure (Single BRT Route / Overlapping BRT Routes / Network of BRT Routes)	Integrated Network of Routes	BRT Route Overlay onto Local Route	BRT Route replaced Local Downtown Circulator	Integrated Network of Routes	Express Routes
Number of Routes Operating in Network	6	1	1	3	4
Number of All-stop Routes	2	1	1	3	-
Number of Express Routes	4	-	-		4
Span of Service (Peak Hour Only / All Day)	All Day	All Day	All Day	All Day	Weekday Peak Hour only
Frequency of Service (Headway during Peak Hour in Minutes)	10	12	5	1	10
Station Spacing (Average Station Spacing in Miles)	0.57	0.56	About 900 feet	0.57 to 1.14	0.25

2.7 INTEGRATION OF BRT ELEMENTS INTO BRT SYSTEMS

BRT may provide significant benefits as a result of its flexibility and the integration of its disparate elements into a package that will yield more total benefits than the sum of the benefits of the individual parts. These elements must be integrated into a system that optimally serves the particular market within the specific physical constraints of each corridor.

There are several primary advantages of BRT's flexibility:

- **BRT elements can be packaged to suit almost any physical and market environment.** It is possible to implement just the elements and the corresponding options that make most sense in a particular community or corridor. This can result in better, more individualized solutions. For instance, investments in ITS traffic signal priority for BRT vehicles may be deemed much more cost efficient than constructing or designating exclusive bus lanes in congested urban areas.

- **BRT systems can be developed incrementally.** Being that each element of BRT can be independently developed, it is also possible to make incremental investments to upgrade the system as ridership grows, public support strengthens, and more resources become available. Additional elements (e.g., off-board fare collection or ITS) could be added or existing system elements could be upgraded to more advanced technologies (e.g., specialized BRT vehicles replacing regular fleet buses).

- **Some elements may be shared with other modes.** BRT can be considered an intermediate mode in the sense that some options may be compatible or even borrowed from other modes. This allows for significant opportunities for joint development and reduced procurement costs with rail and bus projects.

This section explores two primary considerations in integrating BRT elements – developing brand identity for BRT and developing the interface among elements.

2.7.1 Branding for BRT

There is significant flexibility in the way that transit elements can be packaged for a particular BRT system. Each element could be implemented independently, based on what makes the most sense for a particular corridor or what financial resources are currently available. Alternatively, multiple elements can be implemented in an integrated fashion to provide an increased level of quality for the BRT service relative to conventional bus services. Regardless on what elements are included, it is important to develop a strategy to foster a brand for BRT. This section presents a brief introduction to appropriate strategies in developing a unique identity for BRT applications.

When planning for BRT, it is important to note that transit agencies and the services they currently operate, all have a brand identity, whether consciously developed or not. The brand identity is based upon existing characteristics of the system, existing transit services, and existing business processes at the transit agency. The brand identity is not merely visual but relates to the product in relation to the needs and desires of the consumer. Brand identity is communicated visually through names, logos, color schemes, graphics, the design of physical elements, and marketing materials. It is also communicated in all interactions with passengers, potential customers, and others within the BRT market area. Developing a BRT system provides an opportunity to articulate a brand for a unique and distinct system. Because markets are particular to specific regions and evolve over time, the approach to BRT must be tailored to each specific situation.

Since choices involved in branding are particular to a given market for transit service, it is inappropriate to prescribe specific branding strategies. This section describes a typical process to develop a branding strategy. The approach to building a brand for BRT involves three distinct steps.

Research

During the research phase, the implementing agency undertakes activities to understand the target audience. This usually involves the research activities such as surveys, focus groups, and interviews with both users and non-users of transit service. Consumer research reveals demographic information of the market area and what potential consumers perceive about existing transit service and what they would value in a new transit service. Research can also involve an exploration internal to the implementing agency to gauge internal attitudes about provision of service and how business processes affect the end product.

Identification of Points of Differentiation for BRT

The second step in developing the brand involves identifying what the point of differentiation is for BRT. This step involves an exploration of what features are relevant to the target audience. These features can be both related to what the product does (its performance – travel time savings, reliability, safety, security, and effective design) and the impression it conveys. These points of differentiation will help in the planning for the system and selection of elements and ultimately with the marketing of the service.

Implementation of the Brand

Implementation of the brand for BRT can involve at least three activities:

- Implementation of the BRT System Elements – The elements that most support the brand are key to presenting an attractive product that potential customers respond to.
- Changing Internal Business Processes – Critical to a successful product is an organization that believes in the product it is presenting to the customer and delivers the product efficiently and effectively. This often involves reorganization of internal business structures, processes, relationships and delivery approaches.
- Marketing – A good product with a good delivery mechanism is reinforced by an effective marketing campaign. This involves brand identifiers such as distinctive product names, logos, taglines, slogans, color schemes, and livery designs as well as advertising through visual and other media.

2.7.2 Interface Requirements for BRT Elements

Successful implementation of BRT elements requires that elements function seamlessly with other elements. This section presents various combinations of elements and the planning and design issues associated with successful integration of each pair of elements to support BRT system performance and maximize BRT benefits.

Running Ways and Stations

The running way design through a station has particular impacts on the performance and the operation of BRT service. Stations may pose a bottleneck in the system since they are the primary location where vehicles are stopped and encounter delays. The length of the station platform and the width of the running way are the primary factors affecting the extent of delay.

Running Ways and Vehicles

The design of the running ways must accommodate the vehicles that are envisioned to traverse it. Key design interfaces with the vehicles include:

- Clearance for the Vehicle Path – In order to be functional, running ways need to be designed to accommodate the path of the vehicles (often called the “dynamic envelope” of the vehicle) that will operate on it in a safe and efficient manner. The level of guidance can affect the width of the required vehicle path and the right-of-way required.
- Pavement design – BRT vehicles often include features that increase their size and weight. The design of running way pavement determines their ability to accommodate the loads of the BRT vehicles envisioned to operate with the service.
- Guidance – Guidance requires vehicle steering mechanisms to be integrated with markings or infrastructure on the running way

Running Ways and ITS

Traffic signal systems are an integral part of running ways that operate in a street environment. These systems control the flow of all vehicles, including vehicles in BRT service, vehicles in parallel flow, and vehicles crossing the running way. As such, they control how often and at what locations BRT vehicles may conflict with other vehicle traffic and thus the travel time and the need to consider safety of BRT vehicles. Supplementing traffic signal systems with traffic signal priority systems is also an effective way to reduce the potential for running way delays.

Stations and Vehicles

The interface between vehicles and station platform has a strong influence on customer experience and boarding and alighting speed. Primary consideration regarding vehicle and station interface is the height of the BRT vehicle floor and the height and length of the station platform.

Stations and ITS

The provision of ITS elements at BRT stations has a strong positive influence on overall customer experience. The ITS elements commonly employed at BRT stations include real-time variable message signs and advanced electronic off-board fare collection methods and to a lesser extent some type of precision docking technology.

Vehicles and Fare Collection

Vehicle-based fare collection involves the installation of fare collection equipment on the vehicle. Equipment must be installed to ensure ease of use and safety. Equipment for fare verification must be positioned so that BRT vehicle operators can quickly and easily monitor fare transactions. The fare equipment must also be placed to minimize the flow of passengers on and off the vehicle.

Also, off-board fare collection is closely related to the number of door and door streams and their distribution along the length of the vehicle. Without off-board fare collection, multiple stream doors will have a less positive impact on passenger service and dwell times.

Stations and Fare Collection

If fare payment does not take place on-board the vehicle, fare collection considerations including pre-payment equipment and other fare services may be important in the design of station areas. The location of these facilities should be a consideration in both station and fare system design. The amenities provided at a station may also be integrated to the fare system by utilizing the same fare media and payment network. The design of the platforms may also affect the possibility of multi-door boarding associated with pre-payment options. Lastly, passenger security may also be a point of integration for fare collection and station design.

Fare Collection and ITS

ITS technologies may be integrated with fare systems in the collection and management of data. For instance, an EFC system may be linked to an automated vehicle location/GPS system to provide data on the boarding profile along a BRT route. This information would support operations and planning. There may also be opportunities for integrating surveillance technologies for security and enforcement purposes.
Include brief discussion on integration with other elements

Vehicles and ITS

Increasingly, many elements of ITS are being incorporated into vehicle designs. These include traffic signal priority transponders, collision warning devices and other assist and automation (intelligent vehicle) technologies, advanced communication systems, automatic vehicle location, on-vehicle variable message signs for real-time service information, and passenger counters. All of these elements must be mounted on the vehicles and must withstand the physical demands of being placed on the vehicles including vibration and exposure to elements. Since many of these elements must also communicate with each other for full functionality, the installation must account for physical (wire) communications links between them.

3.0 BRT ELEMENTS AND SYSTEM PERFORMANCE

This chapter identifies five key BRT system performance attributes, including: (1) Travel Time, (2) Reliability, (3) Image and Identity, (4) Passenger Safety and Security, and (5) System Capacity. Accompanying each indicator is a description of the performance attribute and a short discussion of the performance of existing systems. This discussion includes a Research Summary (in cases where applicable applications in transit demonstrate effects on performance), System Performance Profiles (short case studies of BRT and non-BRT applications) and a summary of BRT Elements by System and the specific performance attribute.

Travel Times: The impact of BRT systems on travel time saving is dependent on how each BRT element is implemented in the specific application and how they relate to each other and the rest of the BRT system. There are several different travel time components that BRT systems impact, including:

- **Running Time** - The time BRT vehicles and passengers actually spend moving. Running times are dependent on traffic congestion, delays at intersections, and the need to decelerate into and accelerate from stations.
- **Station Dwell Time** – This measures the time vehicles and passengers spend at stations while the vehicle is stopped to board and alight passengers. Typical influences on dwell times include platform size and layout, vehicle characteristics (e.g., floor height, number of doors and their width), fare collection processes and media, and \ the use of technologies to expedite the boarding process for disabled customers and other mobility-impaired group (e.g., precision docking or facilitated wheelchair securement).
- **Waiting and Transfer Times -** These are highly dependent on service frequency and route structure and the design of stations at transit terminals.

Reliability, is defined as the variability of travel times, and is affected by many BRT features. The three main aspects of reliability include:

- **Running Time Reliability** - The ability to maintain consistent travel times
- **Station Dwell Time Reliability** – The ability for patrons to board and alight within a set timeframe. (Elements that contribute to Station Dwell time include: station platform height, vehicle types, fare collection process and fare media type)
- **Service Reliability** – The availability of consistent service (availability of service to patrons, the ability to recover from disruptions, availability of resources to consistently provide the scheduled level of service).

Identity and Image reflects the effectiveness of a BRT system's design in positioning it in the transportation market place and in fitting within the context of the urban environment. It is important both as a promotional and marketing tool for transit patrons and for providing information to non-frequent users as to the location of BRT system access points (i.e., stops and stations) and routing. Two major elements of BRT system Image and Identity capture its identity as a product and as an element of the urban form:

- **Brand Identity** – A BRT system brand identity reflects how it is positioned relative to the rest of the transit system and other travel options. Effective design and integration of BRT elements reinforce a positive and attractive brand identity that motivates potential customers and makes it easier for them to use the system.

- **Contextual Design -** This measures how effectively the design of the BRT system is integrated with the surrounding urban environment.

Safety and Security for transit customers and the general public can be improved with the implementation of BRT systems, where safety and security are defined as:

- **Safety** – Freedom from hazards as demonstrated by reduced accident rates, injuries, and improved public perception of safety.
- **Security –**Actual and perceived freedom from criminal activities and potential threats against customers and property.

Capacity is defined as the maximum number of passengers that can be carried past a point in a given direction, during a given period along the critical section of a given BRT under specific operating conditions. Virtually all BRT elements affect capacity.

Also accompanying the discussion of each performance element is a summary of BRT elements and performance statistics by system. This summary allows for a comparison of different approaches undertaken by transit agencies to achieve performance and of different performance results across systems.[13]

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[13] *Sources of data on system performance included data requests from transit agencies including the Chicago Transit Authority, the Los Angeles County Metropolitan Transportation Authority; the Massachusetts Bay Transportation Authority in Boston, MA; Port Authority of Allegheny County in Pittsburgh, PA, the Regional Public Transportation Authority in Phoenix, AZ; the Regional Transportation Commission of Southern Nevada in Las Vegas, NV. In addition, the following summary and evaluation reports provided data:*

Baltes, Michael, and Dennis Hinebaugh, National Bus Rapid Transit Institute, **Lynx LYMMO Bus Rapid Transit Evaluation***, Federal Transit Administration and Florida Department of Transportation, Tampa, FL, July 2003*

Baltes, M., V. Perk, J. Perone, and C. Thole, **South Miami-Dade Busway System Summary***, National Bus Rapid Transit Institute, May 2003*

Levinson, H., S. Zimmerman, J. Clinger, J. Gast, S. Rutherford, and E. Bruhn, **Bus Rapid Transit - Implementation Guidelines, TCRP Report 90-Volume II***,Transportation Research Board, Washington, DC, 2003*

Milligan & Company, **Bus Rapid Transit Evaluation of Port Authority of Allegheny County's West Busway Bus Rapid Transit Project***, U.S. Department of Transportation, Washington, DC, April 2003*

Pultz, S. and D. Koffman, Crain & Associates, **The Martin Luther King, Jr. East Busway in Pittsburgh, PA***, U.S. Department of Transportation, Washington, DC, 1987*

Transportation Management & Design, Inc., **Final Report, Los Angeles Metro Rapid Demonstration Program***, Los Angeles County Metropolitan Transportation Authority and Los Angeles Department of Transportation, Los Angeles, CA March 2002*

3.1 TRAVEL TIME

Travel time may be the single attribute of a transit system that customers care the most about, particularly for non-discretionary, recurring trips such as those made for work purposes. Relatively high BRT running speeds and reduced station dwell times make BRT services more attractive for all types of customers, especially riders with other transportation choices. Waiting and transferring times have a particularly important effect, and BRT service plans generally feature frequent, all–day, direct service to minimize them.

The Operational Analysis of Bus Lanes on Arterials[14] indicates that for suburban bus operations, the majority of overall bus travel time (about 70 percent) takes place while the bus is in motion. For city bus operations, particularly within Central Business Districts (CBDs), a lower percentage of overall bus travel time (about 40 to 60 percent) takes place while the bus is in motion. This is due to heavier passenger boarding and alighting volumes per stop, higher stop density, more frequent signalized intersections, more pedestrian interference and worse traffic conditions.

For the purposes of this report, we consider four travel time components:

- **Running Time** – time spent in the vehicle traveling from station to station
- **Dwell Time** – time spent in the vehicle stopped at a station
- **Wait time** – time spent by passengers initially waiting to board a transit service
- **Transfer time** – time spent by passengers transferring between BRT service and other types of transit service

Each of these four types of travel time is described in further detail with a discussion of how BRT elements contribute to reductions in travel time. (One aspect of travel time often mentioned in transportation planning is called access time – the time spent by passengers walking or taking another non-transit mode to reach a particular transit service. It is not discussed here since it is affected by the intensity and distribution of land uses.)

3.1.1 Running Time

Description of Running Time

Running time is the element of travel time that represents the time spent by BRT passengers and vehicles actually moving from station to station. In most cases, the maximum speed of the vehicle itself is not usually a determining factor for running travel times. Vehicles in service in such dense corridors rarely accelerate to the maximum speed of the vehicle before they must decelerate to serve the next station. The major determining factors are the delays that the vehicle encounters along the way including congestion due to

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[14] **Operational Analysis of Bus Lanes on Arterials**, *TCRP Report 26, 1997; Appendix A, p. 58*

other vehicle traffic, delays at intersections for turns, traffic signals and pedestrians, the number of stations a vehicle is required to serve, and the design of the BRT route structure.

Effects of BRT Elements on Running Time

The primary BRT elements that improve travel times relative to conventional bus service are described below.

BRT Elements and Running Time	
Running Way – Running Way Segregation	Running Way Segregation is one of the key BRT elements that affect travel times. **Mixed Flow Lanes with Queue Jumpers –** Queue Jumpers allow vehicles to bypass traffic queues (i.e., traffic backups) at signalized locations or bottlenecks. **Dedicated (Reserved) Arterial Lanes** reduce delays associated with congestion in city streets. Dedicated lanes are often used in conjunction with **Traffic Signal Priority** to minimize unpredictable delays at intersections. **At-Grade Exclusive Transitways** eliminate the hazards due to merging or turning traffic or pedestrians and bicyclists crossing into the middle of the running way, allowing BRT vehicles to travel safely at higher speeds. **Grade-Separated Exclusive Transitways** eliminates all potential delay, including delays at intersections. BRT vehicles are free to travel safely at relatively high speeds from station to station.
Stations – Passing Capability	Stations that allow for passing minimize delays at stations, especially if the service plan includes high frequency operation or multiple routes. Passing capability also allows for the service plan to incorporate route options such as skip-stop or express routes, which offer even lower travel times than routes that serve all stations.
ITS – Transit Vehicle Prioritization	**Transit Vehicle Prioritization**, specifically TSP will enable the BRT vehicle to travel faster along the roadway through increased green time. TSP is especially useful if implemented at key intersections that cause the highest delay. To a lesser extent **Signal Timing/Phasing** could provide similar benefits. Retiming or coordinating signals along a corridor is generally directed at improving all traffic flow, not just transit. **Station and Lane Access Control** can reduce the amount of time a BRT vehicle sits in a queue waiting to enter a dedicated BRT or HOV lane or station.
ITS—Driver Assist and Automation	For those BRT systems operating on narrow roadway ROW (e.g. shoulders), **Lane Assist** can allow the BRT vehicle operator to travel at higher speeds than otherwise would be possible due to the physical constraints of the ROW. **Precision Docking** will enable a BRT vehicle to quickly dock at a BRT station and reduce both Running Travel Time and the Station Dwell Time. Docking technology removes the burden on the BRT vehicle operator of steering the vehicle to within a certain lateral distance from the station platform, allowing for faster approaches to stations.

BRT Elements and Running Time	
Service and Operations Plan – Station Spacing	Reducing the number of stations reduces delay associated with decelerating into and accelerating out of the station and with loading at the station. Cumulatively, the travel time savings associated with widening the station spacing can be significant. BRT systems in North America vary considerably with respect to stop spacing, ranging from about 1,200 feet for the planned system in Cleveland's core to about 7,000 feet for the Transitway system in Ottawa, which has significant coverage in suburban areas.
Service and Operations Plan – Schedule Control Method	When frequencies are high enough, encouraging vehicle operators to travel the route as fast as they can and managing on-time performance through **Headway-Based Schedule Control** can encourage vehicles to travel at the maximum speeds that are possible between stations.

Performance of Existing Systems

Transit agencies have significant experience in achieving travel time savings and increasing the speed of service. This section characterizes this experience in three sections – a summary of relevant research, profiles of noteworthy experience (both BRT and non-BRT), and a summary of characteristics that affect dwell time by BRT system.

Research Summary

Research in transit operations suggests how running times can be reduced through many elements that are incorporated into BRT.

The *Transit Capacity and Quality of Service Manual – 2nd Edition*[15] provides estimated average speeds of buses, as a function of three variables:

- Type of Running Way (e.g., Busway or Freeway HOV Lane, Arterial Street Bus Lane, or Mixed Traffic)
- Average Stop Spacing
- Average Dwell Time per stop

Exhibit 3-1 makes clear that the use of exclusive right-of-way (i.e., no traffic signals) is the most effective way to increase bus travel speeds. All things (e.g., station spacing, fare collection approach, etc.) being equal, BRT revenue speeds on exclusive running ways will compare favorably with most heavy rail and exclusive right-of-way light rail systems.

[15] **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C., Part 4*

Exhibit 3-1: Estimated Average Bus Speeds on Busways or Exclusive Freeway HOV Lanes: assumes 50 mph Top Running Speed of Bus in Lane[16]

Average Stop Spacing, in miles	Average Dwell Time per stop, in seconds				
	0	15	30	45	60
0.5	36 mph	26 mph	21 mph	18 mph	16 mph
1.0	42 mph	34 mph	30 mph	27 mph	24 mph
1.5	44 mph	38 mph	35 mph	32 mph	29 mph
2.0	46 mph	41 mph	37 mph	35 mph	32 mph
2.5	46 mph	42 mph	39 mph	37 mph	35 mph

As shown in Exhibit 3-2, having dedicated bus lanes on arterial streets provides for speeds that are similar to that of street-running light rail systems.

Exhibit 3-2: Estimated Average Bus Speeds on Dedicated Arterial Street Bus Lanes, in miles per hour[17]

Average Stop Spacing, in miles	Average Dwell Time per stop, in seconds					
	10	20	30	40	50	60
0.10	9 mph	7 mph	6 mph	5 mph	4 mph	4 mph
0.20	16 mph	13 mph	11 mph	10 mph	9 mph	8 mph
0.25	18 mph	15 mph	13 mph	11 mph	10 mph	9 mph
0.50	25 mph	22 mph	20 mph	18 mph	16 mph	15 mph

Exhibit 3-3 indicates that in typical mixed traffic conditions, bus speeds are significantly lower than those for BRT, light and heavy rail systems operating on exclusive running ways. This is due to the traffic itself, as well as the time required for the bus to exit / re-enter the traffic stream at each stop.

Exhibit 3-3: Estimated Average Bus Speeds in General Purpose Traffic Lanes, in miles per hour[18]

Average Stop Spacing, in miles	Average Dwell Time per stop, in seconds					
	10	20	30	40	50	60
0.10	6 mph	5 mph	5 mph	4 mph	4 mph	3 mph
0.20	9 mph	8 mph	7 mph	6 mph	6 mph	5 mph
0.25	10 mph	9 mph	8 mph	7 mph	7 mph	6 mph
0.50	11 mph	10 mph	10 mph	9 mph	9 mph	8 mph

Exhibits 3-1 to 3-3 also indicate that stop spacing is the next most significant variable in influencing average bus travel speeds, followed by average dwell time per stop.

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16 **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C., p. 4-46*

17 **Transit Capacity and Quality of Service Manual**, *2nd Edition, p. 4-53*

18 **Transit Capacity and Quality of Service Manual**, *2nd Edition; p. 4-53*

BRT systems improve travel times over conventional bus services through a combination of dedicated running ways, longer station spacing, reduced dwell times at stops (e.g., due to multiple door boarding) and/or ITS applications (e.g., traffic signal priority). Experience in Bus Rapid Transit in the United States suggests that travel time savings is on the order of 25 to 50 percent for recently implemented BRT systems.[19] Findings from eleven international systems in Canada, Brazil, Ecuador, England, and Japan found that speed improvements associated with BRT implementation ranged from 22 percent to 120 percent[20].

Exhibit 3-4 shows BRT speeds related to the spacing of stations.

Exhibit 3-4: Busway and Freeway Bus Lane Speeds as a Function of Station Spacing[21]

Station Spacing (miles)	Stops Per Mile	Speeds (MPH)	
		20-Second Dwell	30-Second Dwell
0.25	4.0	18	16
0.50	2.0	25	22
1.00	1.0	34	31
1.50	0.7	42	38
2.00	0.5	44	40

When determining station spacing, there is a tradeoff between patron accessibility and service speed.

System Performance Profiles

Several systems illustrate the potential of developing combinations of BRT elements to achieve travel time savings.

Metro Rapid, Los Angeles, CA

A combination of increased station spacing and traffic signal priority can clearly impact travel time savings. For the Wilshire/Whittier Boulevards BRT line, overall average travel time savings due to the BRT service during peak periods was 28% compared the previous bus service. The TSP system contributed to 27% of the overall travel time savings. The remaining 73% were due to the BRT elements such as station spacing and location. The Ventura Boulevard BRT line saw similar results

[19] **Bus Rapid Transit: Case Studies in Bus Rapid Transit**, *TCRP Report 90 - Volume I, Appendix A, 2003, p. 51*
[20] ***Bus Rapid Transit – An Overview***, *presentation by Booz Allen Hamilton Inc., Washington, DC, 2000*
[21] **Bus Rapid Transit - Implementation Guidelines**, *TCRP Report 90 – Volume II, 2003*

with a 23% overall travel time reduction and TSP contributing to 33% of the travel time savings.

Martin Luther King Jr. East Busway, Pittsburgh, PA

The Martin Luther King Jr. East Busway provides a fully grade-separated transitway for vehicles traveling between downtown Pittsburgh and eastern suburbs. With the introduction of the busway, several routes which had served the corridor were diverted to the busway to take advantage of the faster speeds and reliability afforded by the busway. Along with the diversion of these routes to the busway, the downtown circulation segments of the routes were also re-aligned. The time required for walk access to service, downtown circulation, and line-haul travel were calculated for six key downtown destinations for both the AM Peak and the PM Peak. In all cases in the AM Peak, the line-haul travel time decreased by an average of 5 or 6 minutes, while downtown circulation time decreased for four out of six locations. Overall, total travel time decreased by an average of 8 minutes out of total travel times of 31 to 34 minutes. Travel time savings for trips during the AM Peak were between 13 and 42%. PM Peak travel time savings were not as notable, about 3.5 minutes on average.[22]

Various ITS Applications (non-BRT Example)

There are other examples of TSP impacting travel time outside of the BRT environment. In Atlanta, GA, MARTA buses yielded a 33% reduction in travel time from 42 to 28 minutes. Phoenix, AZ, saw a 16% reduction in travel time. Finally, after installing a TSP system along the Tualatin Valley Highway in Portland, OR, average bus travel times were reduced 6.4% or 31 seconds per intersection.

BRT Elements by System and Travel Time

Exhibit 3-5 summarizes running travel time savings performance benefits associated with the introduction of new of Bus Rapid Transit (BRT) systems. Several performance indicators were developed to measure travel time performance:

- Peak Hour End-to-End Travel Time – this measure is the average weekday travel time required to complete a one-way trip from the beginning to the end of the line during peak hours.
- Unconstrained End-to-End Travel Time – this measure is the average weekday travel time required to complete a one-way trip from the beginning to the end of the line during non-peak hours of service.

[22] *Pultz, S. and Koffman, D., **The Martin Luther King, Jr, East Busway in Pittsburgh, PA**,U.S. Department of Transportation, Urban Mass Transit Administration, 1987.*

- Minutes per mile – this measure, which is calculated by dividing the average end-to-end time (in minutes) by the end-to-end route distance, reveals the amount of time it takes the vehicle to go one mile.
- Maximum Time on Local Line (peak hour) – this measures the end-to-end travel time on the local line running along the same alignment as the BRT line.
- Travel Time Reduction – this measure is derived by calculating the percentage difference in travel time (peak hour) between a BRT line and a local line that operate along the same alignment and have the same end points (for BRT lines that have no local alternative, the travel time is compared to the systemwide average).

The data shown in Exhibit 3-5 provides some empirical context for assessing the impact of BRT elements on transit performance, and in particular, running times. The table consists of 26 BRT systems that encompass a broad cross-section of treatments. Most of the systems described in the table operate in a mixed flow environment, with several systems including elements that such as queue jumping and Traffic Signal Priority (TSP). Systems that allow BRT vehicles to operate along a segregated running way typically offer greater travel time savings than systems that operate in a mixed traffic environment, particularly during peak hours of the day.

Another important factor impacting running way times is station spacing. In addition to prevailing traffic conditions, maximum speeds are also limited by the distance between stations. This understanding is part of the rationale behind limited or 'skip stop' service, which designates fewer stops along a given distance than traditional local service. Although BRT systems typically have to share lane space with local buses on mixed flow lanes, designing a limited stop or 'skip' stop service can reduce end-to-end travel time, especially when complemented with TSP capabilities. Perhaps the best example of this is the MetroRapid service in Los Angeles, CA. There are currently nine Metro Rapid lines in operation, and these lines provide between a 17% to 29% travel time advantage over local lines operating on the same alignment.

There are several BRT systems that operate on at-grade exclusive and reserved bus lanes in Exhibit 3-5: North Las Vegas MAX, Miami (Local Busway and MAX) and the East Busway, South Busway and West Busway in Pittsburgh. Compared to the systems that operate on mixed lanes, these systems demonstrate higher levels of operating performance, and, as a result, provide greater levels of travel time savings. One way to measure performance is to calculate the amount of time it takes to travel a fixed distance, or, minutes per mile. The East and South Busway, for example, average 1.98 and 2.09 minutes per mile, respectively – which is among the lowest in the study group. This is significantly lower than that of BRT systems that operate within a mixed flow traffic environment. Not surprisingly, these systems offer the greatest time savings benefits as well. The South Busway, for example, provides a 55% travel time savings improvement over the average systemwide minutes per mile for all Port Authority fixed route service.

Exhibit 3-5: BRT Elements by System and Travel Time

	Boston Silver Line	Chicago Western Avenue Express (X49)	Chicago Irving Park Express (X80)	Chicago Garfield Express (X55)	Honolulu City Express A	Honolulu City Express B
Running Way						
Mixed Flow Lanes (mi.)	0.2	18.3	9.0	9.4	19.6	7.0
Designated Lanes (mi.)	2.2					
At-Grade Exclusive Lanes (mi.)						
Grade-Separated Exclusive Lanes (mi.)						
Guidance	-	-	-	-	-	-
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane
ITS						
Vehicle Prioritization	Transit Signal Priority (in 2004)					
Driver Assist and Automation						
Service Plan						
Average Station Spacing (mi.)	0.22	0.47	0.50	0.56	0.54	0.20
Method of Schedule Control	Schedule	Schedule	Schedule	Schedule	Schedule	Schedule
Performance						
Maximum (Peak Hour) End-to-End Travel Time (Min.)	9.6	78	44	44	84	44
Uncongested End-to-End Travel Time (Min.)	9.3	60	31	37	67	42
Minutes per Mile (Peak Hour)	4.05	4.26	4.90	4.66	4.29	6.29
Minutes per Mile (Uncongested)	3.92	3.28	3.45	3.92	3.42	6.00
Travel Time Reduction (By Comparison of BRT Schedule to Local)	26%	15%	25%	20%		20%
Travel Time Reduction (Compared to Systemwide Travel Times)					1%	
Travel Time Reduction (As Measured by Agency)	29%					
Customer Perception of Travel Time	73.2% of passengers rate Travel Time / Directness as Above Average or Excellent					

Exhibit 3-5: BRT Elements by System and Travel Time (Continued)

	Honolulu City Express C	Las Vegas North Las Vegas MAX	Los Angeles Metro Rapid Wilshire	Los Angeles Metro Rapid Ventura	Los Angeles Metro Rapid Vermont	Los Angeles Metro Rapid Crenshaw
Running Way						
Mixed Flow Lanes (mi.)	30.0	2.9	25.7	16.7	11.9	18.8
Designated Lanes (mi.)		4.7			-	
At-Grade Exclusive Lanes (mi.)					-	
Grade-Separated Exclusive Lanes (mi.)					-	
Guidance	-	Precision Docking at Stations	-	-	-	-
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	-	
ITS						
Vehicle Prioritization		Transit Signal Priority(7)	Transit Signal Priority	Transit Signal Priority		
Driver Assist and Automation		Precision Docking	-	-		
Service Plan						
Average Station Spacing (mi.)	0.73	0.84	0.78	1.17	0.67	0.83
Method of Schedule Control	Schedule	Headway	Headway	Headway	Headway	Headway
Performance						
Maximum (Peak Hour) End-to-End Travel Time (Min.)	93	32	86	57	56	76
Uncongested End-to-End Travel Time (Min.)	83	28	67	37	48	55
Minutes per Mile (Peak Hour)	3.10	4.21	3.82	3.41	4.41	4.18
Minutes per Mile (Uncongested)	2.77	3.68	2.98	2.22	3.78	3.02
Travel Time Reduction (By Comparison of BRT Schedule to Local)	7%	35%		23%	25%	18%
Travel Time Reduction (Compared to Systemwide Travel Times)						
Travel Time Reduction (As Measured by Agency)				29%	27%	23%
Customer Perception of Travel Time			Passengers rate Metro Rapid travel time 3.82 out of 5, compared to 3.42 for the former Limited Bus			

Exhibit 3-5: BRT Elements by System and Travel Time (Continued)

	Los Angeles Metro Rapid Van Nuys	Los Angeles Metro Rapid Broadway	Los Angeles Metro Rapid Florence	Orlando LYMMO	Miami Busway Local	Miami Busway MAX	Oakland Rapid San Pablo Corridor
Running Way							
Mixed Flow Lanes (mi.)	21.4	10.5	10.3				14.0
Designated Lanes (mi.)	-	-	-	-			
At-Grade Exclusive Lanes (mi.)	-	-	-	3.0	8	8	
Grade-Separated Exclusive Lanes (mi.)	-	-	-	-			
Guidance	-	-	-	-	-	-	
Passing Capability	-	-	-	-	Bus Pullouts	Bus Pullouts	-
ITS							
Vehicle Prioritization							
Driver Assist and Automation							
Service Plan							
Average Station Spacing (mi.)	1.05	0.69	0.88	About 900 feet	0.54	1.14	0.56
Method of Schedule Control	Headway	Headway	Headway	Headway	Schedule	Schedule	Schedule
Performance							
Maximum (Peak Hour) End-to-End Travel Time (Min.)	98	37	53	20	27	25	63
Uncongested End-to-End Travel Time (Min.)	76	32	38	20	27	25	52
Minutes per Mile (Peak Hour)	4.45	3.36	4.31	6.67	3.38	3.13	4.49
Minutes per Mile (Uncongested)	3.45	2.91	3.09	6.67	3.38	3.13	3.70
Travel Time Reduction (By Comparison of BRT Schedule to Local)	17%	29%	20%	0%			21% (17% reduction from limited route according to Agency measurements)
Travel Time Reduction (Compared to Systemwide Travel Times)					29%	35%	
Travel Time Reduction (As Measured by Agency)		24%	23%				
Customer Perception of Travel Time					59% of passengers rate travel time on the Busway as Good or Very Good (average rating of 3.63 out of 5)		

Exhibit 3-5: BRT Elements by System and Travel Time (Continued)

	Pittsburgh East Busway	Pittsburgh South Busway	Pittsburgh West Busway	Phoenix Rapid I-10 East	Phoenix RAPID I-10 West	Phoenix RAPID SR-51	Phoenix RAPID I-17
Running Way							
Mixed Flow Lanes (mi.)	0.4	-	0.4	6.5	4.8	12.3	8.0
Designated Lanes (mi.)	-	-	-	14.0	8.0	10.3	11.5
At-Grade Exclusive Lanes (mi.)	-	-	-	-	-	-	-
Grade-Separated Exclusive Lanes (mi.)	8.7	4.3	4.6	-	-	-	-
Guidance	8.7						
Passing Capability	Passing Lanes at Stations	Passing Lanes at Stations	Passing Lanes at Stations	bus pullouts	bus pullouts	bus pullouts	bus pullouts
ITS							
Vehicle Prioritization	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)
Driver Assist and Automation	Collision Warning	Collision Warning	Collision Warning	Collision Warning	Collision Warning	Collision Warning	Collision Warning
Service Plan							
Average Station Spacing (mi.)	1.14	0.54	0.83	1.86	1.59	2.05	1.63
Method of Schedule Control	Schedule	Schedule	Schedule	Schedule	Schedule	Schedule	Schedule
Performance		-	-				
Maximum (Peak Hour) End-to-End Travel Time (Min.)	20	9	17	37	34	48	52
Uncongested End-to-End Travel Time (Min.)	18	9	14				
Minutes per Mile (Peak Hour)	2.20	2.09	3.40	1.80	2.62	2.49	2.67
Minutes per Mile (Uncongested)	1.98	2.09	2.80	-	-	-	-
Travel Time Reduction (By Comparison of BRT Schedule to Local)							
Travel Time Reduction (Compared to Systemwide Travel Times)	52%	55%	26%	-	-	-	-
Travel Time Reduction (As Measured by Agency)							
Customer Perception of Travel Time			85% of passengers report shorter travel times with an average reduction of 14 minutes				

3.1.2 Station Dwell Time

Description of Station Dwell Time

Station dwell time is the amount of time spent by passengers while a vehicle is stopped at a station. The dwell time represents the time required for the vehicle to load and unload passengers at the transit station. The report on *Operational Analysis of Bus Lanes on Arterials* states that station dwell time can comprise as much as 30% (a significant share) of total travel times for transit. It also states that dwell time can also make up to as much as 40% of total delay time depending on the level of congestion. Dwell time depends on:

- the number of passengers boarding or alighting per door channel – multi-door boarding disperses passengers
- the fare collection system – pre-processing fares and/or reducing transaction times on vehicles can reduce loading times
- vehicle occupancy – congestion inside the vehicle requires extra time to load and unload passengers.

The dwell time at a particular stop can be estimated by multiplying the number of people boarding and/or alighting through the highest volume door by the average service time per passenger. Typical dwell times for standard local bus operations are:

- About 60 seconds at a downtown stop, transit center, major transfer point, or major park-and-ride stop
- About 30 seconds at a major outlying stop
- About 15 seconds at a typical outlying stop

Several bus rapid transit elements can reduce station dwell times significantly.

Effects of BRT Elements on Station Dwell Time

The BRT elements that impact station dwell time most strongly are discussed below.

BRT Elements and Station Dwell Time	
Stations – Platform Height	**Level Platforms** minimize the "gap" between the BRT vehicle floor and station platform edge, greatly speeding the boarding and alighting process. For example, the MAX system in Las Vegas and the TEOR system in Rouen, France utilize an optical guidance precision docking system. This system and vehicle floor-height station platforms provide level, no-gap boarding and alighting, thus greatly reducing station dwell times. No-gap, level vehicle floor -to-platform boarding and alighting has the added benefit of permitting wheelchair users to board and alight BRT vehicles without a lift, ramp, or assistance from a vehicle operator. **Raised Curbs** achieve some of the benefits of level platforms without the need for precision docking but require extra time for ramp deployment for the mobility impaired.

BRT Elements and Station Dwell Time

Stations – Platform Layout	Platform layouts that do not constrain the number of vehicles that can load and unload passengers decrease the amount of time vehicles spend at stations waiting in vehicle queues.
Vehicles – Vehicle Configuration	Vehicle configurations with low floors facilitate boarding and alighting, especially of mobility impaired groups – the disabled, elderly, children, and persons with packages. For low floor vehicles passenger service times could be reduced 20% for boarding times, 15% for front alighting times and 15% for rear alighting times. **Specialized BRT Vehicles** with one hundred percent low floor vehicles have the great advantage of shorter boarding and alighting times and the ability to place an additional door behind the rear axle.
Vehicles – Passenger Circulation Enhancement	All types of passenger circulation facilitate lower dwell times. **Additional Door Channels** (with wider and more numerous doors) can dramatically reduce the time for passengers to board and alight. BRT systems that incorporate some form of secure, non-driver involved fare collection can take advantage of multiple-door boarding. Vehicles that include **Alternative Seat Layout** with wider aisles in the interior also promote reduced dwell times, especially when there are significant standing loads. Although a small percentage of passengers board in wheelchairs, the dwell times for these customers can be significant. The typical wheelchair lift cycle-times range from 60 to 200 seconds per boarding for high floor buses (including time to secure the wheelchair). With a low floor bus the typical wheelchair ramp cycle time ranges from 30 to 60 seconds per boarding which includes time to secure the wheelchair. **Enhanced Wheelchair Securement** devices are being developed and can reduce dwell times further. The extent of the impact is still being measured.
Fare Collection – Fare Collection Process	Fare Collection Processes that allow multiple door boarding – **Proof-of-Payment** and **Barrier-Enforced Pre-Payment** – can provide significant reductions in boarding times. According to the *Transit Quality of Service Manual (2nd Edition)*, proof-of-payment systems can provide up to a 38% reduction in boarding times, and therefore commensurate reductions in dwell times as well. Multiple door channels for boarding and alighting can reduce passenger service times even further, to a fraction of other fare collection approaches. For example, two, three, four, and six door channels can reduce the 2.5 seconds per total passenger required to board under complete pre-paid fare system to 1.5, 1.1, 0.9, and 0.6 seconds per total passenger boarding at a particular stop, respectively.[24]

[23] **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C.*

[24] **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C., Exhibit 4-2.*

BRT Elements and Station Dwell Time	
Fare Collection – Fare Transaction Media	For options where fare transactions take place on the vehicle, the fare transaction media has additional impacts on station dwell time. Compared to fare collection by a driver using exact change, flash pass systems or electronic systems using tickets or passes can reduce passenger boarding time by 13% from an average of 3.5 to 4 seconds per passenger.[25] **Smart Card** technologies are most effective in this respect; **Magnetic Stripe Card** technologies are less effective. In addition, electronic systems can offer a great amount of valuable passenger level data for better scheduling and planning. This can further reduce passenger travel times.
ITS—Driver Assist and Automation	**Precision Docking** has the potential to reduce station dwell times for two reasons. First, it allows all passengers, especially the mobility impaired, to board and alight without climbing up and/or down stairs. Second, some BRT systems (e.g., Bogotá Transmilenio) use systems that ensure that vehicles stop in the same location, thus insuring orderly queuing for boarding.
Service and Operations Plan – Service Frequency	Increasing service frequency reduces the number of passengers that can accumulate at the station, reducing the time associated with loading them.
Service and Operations Plan – Method of Schedule Control	Headway-based schedule control makes headways more regular, ensuring even loads and loading times.

Performance of Existing Systems

BRT elements have achieved reductions in dwell time from conventional transit. This section characterizes this experience in three sections – a summary of relevant research, profiles of noteworthy experience, and a summary of characteristics that affect dwell time by BRT system.

Research Summary

Several studies performed for conventional transit service suggest how implementation of certain BRT elements can achieve dwell time savings.

Exhibit 3-6 highlights typical passenger services times for a standard floor bus. Exhibit 3-7 shows loading times as a function of available door channels. Increasing the number of door channels available for loading does reduce loading time. This is critical where the number of passengers at stations is high.

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[25] **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C., Exhibit 4-2.*

Exhibit 3-6: Passenger Service Times by Floor Type[26]

Transit Agency	Boarding Times (Seconds)		Alighting Times (Seconds)	
	Low-Floor	High-Floor	Low-Floor	High-Floor
Ann Arbor Transportation Authority				
Revenue: Cash	3.09	3.57	1.32	2.55
No Cash	1.92	2.76	2.17	2.67
Shuttle: No Fare	1.91	2.26	Not Reported	Not Reported
Victoria Regional Transit system	3.02	3.78	1.87 2.13	3.61 1.84
Vancouver Regional Transit System	Not Applicable	3.78	Not Applicable	2.62 1.43
St. Albert Transit				
Single Boarding	3.61	4.27		
Two Boarding	6.15	7.27	Not Reported	Not Reported
Senior Boarding	3.88	6.10		
Kitchner Transit	2.23	2.42	1.16	1.49

Sources: References 1, 13 and 26

Exhibit 3-7: Multiple Channel Passenger Service Times per Total Passenger with a High Floor Bus[27] (seconds/passenger)

Available Door Channels	Boarding	Front Alighting	Rear Alighting
1	2.5	3.3	2.1
2	1.5	1.8	1.2
3	1.1	1.5	0.9
4	0.9	1.1	0.7
6	0.6	0.7	0.5

The *Transit Capacity and Quality of Service Manual – 2nd Edition* estimates the average boarding times per passenger for a conventional single-door boarding bus fare collection system where the operator(s) enforces fare payment. These are shown in Exhibit 3-8:

26 **Bus Rapid Transit: Case Studies in Bus Rapid Transit**, *TCRP Report 90, Chapter 6*

27 **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C.*

Exhibit 3-8: Bus Passenger Service Times (Seconds/Passenger)[28]

Fare Payment Method	Observed Range	Default (Single-Door Boarding)
BOARDING		
Pre-payment (e.g., passes, no fare, free transfer and pay on exit)	2.25–2.75	2.5
Smart card	3.0–3.7	3.5
Single ticket or token	3.4–3.6	3.5
Exact change	3.6–4.3	4.0
Swipe or dip card	4.2	4.2
ALIGHTING		
Rear door	1.4–2.7	2.1
Front door	2.6–3.7	3.3

Notes:
** Add 0.5 seconds to boarding times if standees are present on the bus.*
***Subtract 0.5 seconds/passenger from boarding times and 1.0 seconds/passenger from front-door alighting times on low-floor buses.*

System Performance Profiles

Ottawa Transitway, Ottawa, Ontario, Canada

The Ontario Phase III Demonstration Project, conducted from April 1982 to March 1984, involved replacing standard 40-foot buses with 60-foot articulated buses on one OC Transpo route in Ottawa-Carleton and the introduction of a proof-of-payment (POP) fare collection scheme. Under this proof-of-payment fare collection scheme, passengers with valid passes or transfers (about 68 percent of riders on the route) could board at any of the three doors of the articulated bus. Prior to POP implementation, the bus operator enforced fare payment on this route and all passenger boardings took place only at the front door.

Due to the increased capacity of the articulated buses, OC Transpo was able to substitute two articulated buses for three standard buses on the route – with benefits realized from fewer driver hours and reduced operating costs. The demonstration project also showed that POP implementation yielded better performance, through improvements in schedule adherence and on-time performance. Average dwell times for the articulated buses were reduced by an estimated 13-21 percent, based on dwell time survey data. Average bus running times were reduced by about 2 percent. There was no evidence that POP implementation increased the fare evasion rate.

28 **Transit Capacity and Quality of Service Manual**, *2nd Edition, p. 4-5;*
BRT Implementation Guidelines, *TCRP Report 90-Volume II, Table 8-7*

BRT Elements by System and Station Dwell Time

Exhibit 3-9 presents a summary of BRT system characteristics that affect station dwell time. A focus on reducing dwell times is not yet standard among BRT systems. Many BRT systems, especially those that operate on arterial streets load and unload passengers in the same fashion as conventional bus service, yielding minimal dwell time reductions. BRT systems in operated by AC Transit, the Chicago Transit Authority, Honolulu's TheBus and the Los Angeles Metro will incorporate smart cards as part of systemwide implementations.

Variations in the fare payment process yield dwell time reductions. Orlando's Lymmo operates with no fares and therefore allows passengers to enter and exit through all doors. Pittsburgh's busways follow a policy of collecting fares on trips away from downtown at the destination station. Passengers thus board through all doors in downtown, speeding up the service as it travels through downtown. The MAX system in Las Vegas is the only operable system in the United States that uses pre-payment of fares, multiple-door boarding, and level platforms as part of a comprehensive design to reduce dwell times.

Exhibit 3-9: BRT Elements by System and Station Dwell Time

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Neighborhood Express	CityExpress!	North Las Vegas MAX	Metro Rapid
Stations					
Platform Height	Standard Curb	Standard Curb	Standard Curb	Level Platform	Standard Curb
Platform Layout (No. of Vehicles Accommodated)	1	1	1	1	1
Vehicles					
Vehicle Configuration	Specialized BRT Vehicle	Conventional Standard (40')	Conventional Articulated (60')	Conventional Articulated (60')	Conventional Standard (40')
Passenger Circulation Enhancements				Alternative Layout	
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Proof-of-Payment	Pay On-Board
Fare Media	Cash & Paper	Cash & Paper; Magnetic Stripe	Cash & Paper	Cash & Magnetic Stripe	Cash & Paper
ITS					
Vehicle Prioritization	Transit Signal Priority (in 2004)			Transit Signal Priority (7)	Transit Signal Priority
Driver Assist and Automation				Precision Docking	-
Service and Operations Plan					
Service Frequency (Peak)	4	9 to 12	11	12	2 to 30
Method of Schedule Control	Schedule	Schedule	Schedule	Headway	Headway
Performance					
Average Dwell Time				15 to 20 seconds	
Maximum Dwell Time					

Exhibit 3-9: BRT Elements by System and Station Dwell Time (Continued)

	Orlando LYMMO	Miami Busway	Oakland Rapid Bus	Phoenix Rapid	Pittsburgh Busways
Stations					
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Layout (No. of Vehicles Accommodated)	2	3	1	1	2-3
Vehicles					
Vehicle Configuration	Standard (Mini)	Conventional Standard (Mini and 40') and Articulated	Stylized Standard	Specialized Standard	Conventional Standard & Articulated
Passenger Circulation Enhancements					
Fare Collection					
Fare Collection Process	N/A (Free Fares)	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	N/A	Cash, paper swipe card	Cash & Paper	Cash, Magnetic Stripe	Cash & Paper
ITS					
Vehicle Prioritization		Transit Signal Priority		Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)
Driver Assist and Automation				Collision Warning	Collision Warning
Service and Operations Plan					
Service Frequency (Peak)	10	12	5	10	1
Method of Schedule Control	Headway	Schedule	Headway	Schedule	Schedule
Performance					
Average Dwell Time		45 to 60 sec			35-36 s at inner stations; 47-60 s at outer stations of East Busway
Maximum Dwell Time		120 sec			

3.1.3 Wait Time and Transfer Time

Description of Wait Time and Transfer Time

The **wait time** is the amount of time passenger spends at a station before boarding a particular transit service. Because passengers perceive wait time as more of a burden than time spent in a moving vehicle (as much as three times a burden), reducing wait time is an important aspect of designing a BRT service. BRT systems are often planned such that the base, all stops service is frequent enough during peak periods that customers without a schedule can arrive randomly and still experience brief waits.

Transfer times represent the amount of time passengers spend transferring from one BRT service to another or to other transit services (e.g., local bus routes and rail). Reducing the time required to travel within the station from one vehicle to the next and the time spent waiting for the second service reduce this element of Travel Time.

Effects of BRT Elements on Wait Time and Transfer Time

Service frequency and reliability are the primary determinants of wait time, although other elements, such as ITS (passenger information systems), affect the perception of wait time. In addition to those factors that affect wait time, station physical design and transit route network design are the primary factors affecting transfer time in BRT.

BRT Elements and Wait Time and Transfer Time	
Stations – Station Type	The design of interchange stations can facilitate lower transfer times, walking distances, and fewer level changes.
ITS—Operations Management	An **Automated Scheduling and Dispatch System** along with **Transit Vehicle Tracking** insures even headways (for lower wait times) and connection protection for those passengers transferring among systems or vehicles. Transit Vehicle Tracking also enables the passenger information to be collected and disseminated.
ITS—Passenger Information	Real-time passenger information systems do not directly impact wait time. By providing current information on the status of the approaching vehicles, real-time passenger information systems do allow passengers to change their wait time expectations, reducing the burden that passengers associate with waiting. **Trip Itinerary Planning** and **Traveler Information on Person** (through PDAs or mobile phones) give passengers advance information on closest stations, next vehicle arrival, and required transfers. **Traveler Information on Vehicles** and **Traveler Information at Stations** can inform passengers on next vehicle arrival and can direct passengers to the correct location for transfers (berth or platform position.)
Service and Operations Plan – Service Frequency	Service Frequency is the key determinant of Wait Time and Transfer Time. Since standard size vehicles can be used in BRT systems, they can often sustain high frequencies.

BRT Elements and Wait Time and Transfer Time	
Service and Operations Plan – Route Structure	BRT route structures that incorporate multiple route types that converge onto a common trunk can increase the number and types of services available to transit passengers at high volume stations. Multiple routes traveling the same corridor increase the frequency along the corridor and reduce the amount of time waiting for BRT service. BRT route networks can also be constructed to eliminate transfer time altogether. Routes can combine local feeder and BRT trunk service, eliminating the need to disembark at the station and transfer for passengers who access the transit network at locations away from the primary BRT route.
Service and Operations Plan – Method of Schedule Control	For high frequency services, Headway-based scheduling can regulate headways and reduce spikes in waiting time due to vehicle bunching.

Performance of Existing Systems

System Performance Profiles

Several systems suggest how BRT elements can reduce wait times and transfer times.

South Busway, Miami, Florida

The existing 8.5-mile portion of the Busway is a two-lane, at-grade, bus-only roadway constructed in a former rail right-of-way adjacent to US 1. Six bus routes operate on all or part of the Busway including express buses on the exclusive lanes moving passengers to and from the Dadeland South Intermodal Metrorail Station in just about 25 minutes. Since all six route converge onto the same busway trunk, they provide a combined frequency during the peak hour of vehicles per hour, making wait time insignificant. The Dadeland South Intermodal Metrorail Station offers a seamless connection between rail and busway passengers. The Metrorail has an enclosed fare area. Passengers must exit the Metrorail fare area, however, to access the Busway bays for boarding and alighting.

Portland, OR (non-BRT application)

Two technologies impacting wait time include vehicle location and traveler information, Measuring the impact of these technologies Wait Time can be difficult to collect and measure. One comprehensive evaluation of the Tri-Met vehicle location system in Portland, OR, produced an estimated annual system-wide savings in wait time of $1.6 million. This was based upon eight routes, an average wage of $14.10 per hour and 62.2 million annual weekday boardings. This system did not include traveler information on the vehicle or at the stop and was a result of better monitoring of vehicle location.

London Bus, London, England (non-BRT application)

In London, England, an evaluation of the London Transport Countdown System (a real-time bus arrival information system) revealed that 83% of those surveyed believed that time passed more quickly by having the real-time information system at the stop. Also, 65% of those surveyed felt they waited a shorter time with the average perceived wait time dropping from 12 minutes to 8.5 minutes, a 28% reduction.

BRT Elements by System and Wait Time and Transfer Time

Exhibit 3-10 presents those characteristics of BRT systems that affect the time associated with waiting for transit service and transferring between services. As expected, systems where the frequency was improved and spacing between vehicles was regulated yielded positive passenger ratings of wait time. Integrated networks such as Pittsburgh's Busways resulted in reduced wait time along trunk segments and reduced time associated with transferring. Many passengers do not have to transfer at all while passengers who do still transfer report improvements in the ease of transferring.

Exhibit 3-10: BRT Elements by System and Wait Time and Transfer Time

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Neighborhood Express	CityExpress!	North Las Vegas MAX	Metro Rapid
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station	Enhanced Shelter
ITS					
Driver Assist and Automation				Precision Docking	-
Operations Mgmt.	Advanced Communication, Auto Dispatch, AVL	AVL		Advanced Communication, Auto Dispatch, AVL	Advanced Communication, Auto Dispatch, AVL
Passenger Information	Station, Telephone	Station	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet
Service Plan					
Route Structure		Single Route Overlay onto Local Network		Single Route Overlay onto Local Network	Single Route Overlay onto Local Network
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Hour Headway)	4 min.	9 to 12 min.	11 min.	12 min.	2 to 30 min.
Method of Schedule Control	Schedule	Schedule	Schedule	Headway	Headway
Performance					
Measured Impacts					
Customer Perception of Wait Time and Transfer Time	60.2% of surveyed passengers rated Frequency of Service Above Average or Excellent				Passengers rate Metro Rapid Frequency Buses 3.76 out of 5, compared to 3.15 for the former Limited Bus

Exhibit 3-10: BRT Elements by System and Wait Time and Transfer Time (Continued)

	Miami Busway	Oakland Rapid Bus	Orlando LYMMO	Phoenix Rapid	Pittsburgh Busway
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station
ITS					
Driver Assist and Automation				Collision Warning	Collision Warning
Operations Mgmt.	Auto Dispatch, Vehicle Monitoring, AVL	Automated Dispatch, AVL, Vehicle Monitoring	AVL	Automated Dispatch, AVL	AVL
Passenger Information	Station, Person, Vehicle	Station, Itinerary	Station, Vehicle, PDA	Station, Vehicle, PDA, Internet	
Service Plan					
Route Structure				Express Single Route	Integrated Network
Service Span	All Day	All Day	All Day	Weekday Peak Hour Only	All Day
Service Frequency (Peak Hour Headway)	10 min.	12 min.	5 min.	10 min.	1 min.
Method of Schedule Control	Schedule	Headway	Headway	Schedule	Schedule
Performance					
Measured Impacts	44% of passengers on Busway routes do not require a transfer to complete the busway trip				
Customer Perception of Wait Time and Transfer Time	44% of passengers rate the frequency of service as good or very good (average rating = 3.25 out of 5)				78% of passengers perceived reduced wait time; 52% of passengers reported that transferring had gotten easier due to high frequency of EBA route

3.2 RELIABILITY

Passengers are attracted to trips with short travel times, but they are more likely to continue using the service if it is something they can depend upon. Systems that do not provide a consistent level of service will have difficulty retaining potential passengers who have other transportation choices. Travel time reliability is affected by a number of sources of uncertainty, including traffic conditions, vehicle breakdowns due to unforeseen mechanical or non-mechanical problems, route length, recovery times built into the route schedules, number of stops, evenness of passenger demand, and the unpredictable use of wheelchair lifts/ramps.

Some of these factors are not within the direct control of the transit operator. Nevertheless, there are many features of BRT that improve reliability. In this discussion, we focus on three main aspects of reliability – running time reliability, station dwell time reliability, and service reliability. The first two relate to a system's ability to meet a schedule or a specified travel time consistently, while service reliability captures the characteristics of the system that contribute to passengers perception of service availability and dependability.

3.2.1 Running Time Reliability

Description of Running Time Reliability

Running time reliability relates the ability of a BRT service's ability to maintain a consistently high speed in order to provide customers with consistent travel times. Maintaining running time reliability is important since it reinforces the idea that a passenger can depend upon a BRT system consistently.

Effects of BRT Elements on Running Time Reliability

All of the running way characteristics that contribute to reductions in running way travel time can also improve reliability.

BRT Elements and Running Time Reliability	
Running Way – Running Way Segregation	Running way segregation reduces the number of unpredictable delays at intersections and along the running way reduce the variability of the trip times. Reliability is greatest for fully grade-separated exclusive running ways since complete segregation effectively eliminates conditions that cause delay (traffic congestion, exposure to accidents).
Stations – Passing Capability	Designing stations so vehicles can pass other vehicles at stations allows vehicles that have already completed loading at the station or that serve routes that bypass the station to continue on their journeys and maintain their schedule without delay.

BRT Elements and Running Time Reliability	
ITS –Vehicle Prioritization	**Transit Signal Priority** systems allow a BRT vehicle to maintain its schedule by giving those BRT vehicles that are behind schedule extra green time. **Signal Timing / Phasing** can give more overall green time to BRT vehicles operating at peak times in the peak direction. **Station and Lane Access Control** reduces the number illegal vehicles operating on the facility by restricting access to facilities and stations to authorized BRT vehicles
ITS—Driver Assist and Automation	**Collision Warning, Lane Assist** and **Precision Docking**, give the BRT vehicle operator added insurance to operate at consistent speeds regardless of traffic condition thereby insuring overall system reliability by maintaining a schedule.
ITS—Operations Management	**Vehicle Tracking, Scheduling and Dispatch**, and **Mechanical Monitoring and Maintenance** enable a central dispatcher to know exactly what is happening to address the situation as needed. And if there were an incident, such as a mechanical failure, accident or congestion, these systems allow a central dispatcher to address problems quickly and efficiently in order to insure the reliability of the system.
Service and Operations Plan – Station Spacing	Spacing stations further apart improves reliability for the same reasons that it improves running travel time: • Significant distances between stations allow vehicles to travel at a predictable, high speed for longer periods of time • Serving fewer stations concentrates demand at each station, reducing the opportunities for variation due to starting and stopping and loading and unloading.
Service and Operations Plan – Route Length	Running time reliability is more possible with shorter route lengths, especially for BRT systems that have minimal running way segregation.

Performance of Existing Systems

The experience with systems that explicitly are meant to improve reliability is limited. Traditionally, transit planners have focused on other measures of performance. Increasingly, researchers are now focusing on reliability as a significant factor in attracting customers. This section presents profiles of systems that are good illustrations of achieving reliability and a summary of BRT elements that affect reliability by system.

System Performance Profiles

Applications of BRT elements and demonstrated performance provide good examples to planning for reliability.

Wilshire Boulevard Dedicated Lane Demonstration Project, Los Angeles, CA

The Wilshire Boulevard Dedicated Lane Demonstration Project involved the implementation in Spring 2004 of peak-period (weekdays from 7:00 am to 9:00 am and 4:00 pm to 7:00 pm) curb bus-only lanes in each direction of traffic on a 0.9 mile section of Wilshire Boulevard between Federal and Centinela Avenues in West Los Angeles. Prior to bus lane implementation, curbside parking was allowed and Los Angeles Metro buses operated in mixed-flow traffic during the peak periods.

Four days of on-board survey data (two days before project implementation; two days after implementation) and two months of loop detector data (one month before; one month after) were analyzed to assess the demonstration project's impact on bus running times in the segment. Running times were reduced during each hour of the peak period in both directions of traffic, by an average of about 7 percent. Running time reliability (i.e., the range between the 5^{th} and 95^{th} percentiles of travel time observations) also improved in nearly all times of the day, by an average of about 17 percent.

98 B-Line, Vancouver, British Columbia, Canada

The 98 B-Line is one of three BRT lines that operate on arterial streets in Vancouver, British Columbia, Canada. The three lines together service over 49,000 riders a day. Each route is provided with frequent service, limited stop operation, and dedicated low-floor articulated buses. Opened in August 2001, the 98 B-Line also features distinct high quality shelters and stops, transit priority measures (median busway, AVL/CAD, and transit signal priority) and real-time next bus arrival information at each stop.

The 98 B-Line improved reliability for transit customers while creating virtually no impediment to other travel modes in or across the corridor. Although there was limited change in the actual travel times comparing conditions before BRT implementation and after B-Line implementation, travel time variability decreased by 40 to 50% in all periods of the day and in both directions of travel. In addition, even though a direct automobile trip retains shorter travel times in the corridor (28.9 minutes for automobile v. 42.1 minutes for transit), the transit trip is more reliable than the automobile. For example, the standard deviation of the automobile trip is 5.3 minutes while the standard deviation for the transit trip is 2.8 minutes in the AM Peak in the Northbound direction. [29]

Various Operations Management Applications, (Non-BRT Applications)

Two technologies that have the largest impact on system reliability include vehicle location system and transit signal priority. A vehicle location system can reduce bus bunching, improve bus spacing and improve schedule adherence resulting in increased system reliability. In Portland, OR, bus spacing improved 36% after Tri-

29 *"98 B-Line Bus Rapid Transit Evaluation Study", IBI and Translink, September 29, 2003, p. 34.*

Met utilized vehicle location data to adjust headway and run times. Also, on-time performance improved from 70% to 83% for one route once vehicle location data was available. Baltimore, MD demonstrated a 23% increase in on-time performance of those buses equipped with vehicle location technology. And, in Kansas City, MO, on-time performance improved from 80% to 90% with a 21% reduction in late buses and a 12% reduction in early buses after implementing a vehicle location system

Just as transit signal priority reduces overall travel time, TSP can also improve system reliability by reducing vehicle delay and stops. In Phoenix, AZ, TSP reduced red light delay by 16%. However, overall trip times were not reduced since buses dragged in order to maintain operating schedules. This is a case where policy decisions impact the effectiveness of a technology and must be taken into account in the operation of a BRT system. An evaluation of the Toronto TSP system demonstrated a 32% to 50% reduction in signal delay for various bus routes.

BRT Elements by System and Running Time Reliability

Exhibit 3-11 provides a summary of running time reliability performance of 26 recently deployed BRT systems. The performance indicators developed to measure running time reliability include:

- Maximum End-to-End Travel Time – this measure is the average weekday travel time required to complete a one-way trip from the beginning to the end of the line during peak hours.

- Unconstrained End-to-End Travel Time – this measure is the average weekday travel time required to complete a one-way trip from the beginning to the end of the line during non-peak hours of service.

- Ratio of Unconstrained to Maximum Travel Time – this measures the travel time differential between peak and non-peak travel times. The higher the ratio, the greater the impact of peak hour traffic conditions on end-to-end travel times, especially for systems that operate in mixed traffic corridors.

Running time reliability describes the ability of a BRT system to maintain a consistently high speed in order to provide customers with consistent travel times. The system characteristics that impact running way travel time such as running way segregation, ITS and station spacing also affect running time reliability.

Exhibit 3-11 summarizes running time reliability performance for the 26 new BRT systems in the study group. The key performance indicator in this table is "Ratio of Maximum Time to Unconstrained Time." Typically, this ratio is lower for BRT systems that operate along dedicated or exclusive lanes than those systems that operate within a mixed flow environment. Exhibit 3-11 shows that segregating BRT service from mixed flow traffic – which is subject to deteriorating levels-of-service (LOS) during peak hours – allows the service to sustain a higher and more consistent level of performance over the entire service span. Of the 7 systems that operate on dedicated or exclusive lanes, this ratio ranges between a high of 1.26 (North Las Vegas MAX) to a low of 1.00 (LYMMO, Miami Local, Miami Busway MAX and the South Busway in Pittsburgh). Systems with a ratio of 1.00 indicate that travel times are not impacted by prevailing traffic conditions, and can maintain high and consistent level of performance throughout the service day.

For systems that operate along mixed flow lanes, this ratio was typically higher, particularly in regions suffering from heavy local traffic conditions. Los Angeles' Metro Rapid system, for example, have a range between 1.17 for the Metro Rapid Vermont line to 1.54 for the Metro Rapid Ventura line. Metro Rapid service is equipped with TSP, which can partially offset some of the travel time variability associated with operating service on highly congested major arterial roads. The systems with the three highest ratios are the Metro Rapid Ventura (1.54), the Irving Park Express in Chicago, IL (1.42) and the Western Avenue Express in Chicago, IL (1.30). All three are systems that operate on major arterial roads subject to recurring peak hour traffic congestion.

Exhibit 3-11: BRT Elements by System and Running Time Reliability

	Boston	Chicago	Chicago	Chicago	Honolulu	Honolulu	Honolulu	Las Vegas	Los Angeles
	Silver Line	Western Avenue Express (X49)	Irving Park Express (X80)	Garfield Express (X55)	City Express A	City Express B	City Express C	North Las Vegas MAX	Metro Rapid Wilshire
Running Way									
Mixed Flow Lanes (mi.)	0.2	18.3	9.0	9.4	19.6	7.0	30.0	2.9	25.7
Designated Lanes (mi.)	2.2							4.7	
At-Grade Exclusive Lanes (mi.)									
Grade-Separated Exclusive Lanes (mi.)									
ITS									
Vehicle Prioritization	Transit Signal Priority (2004)							Transit Signal Priority (7)	Transit Signal Priority
Driver Assist and Automation								Precision Docking	-
Operations Mgmt.									Advanced Communication, AVL
Service Plan									
Route Length	2.37	18.3	8.98	9.44	19.6	7.0	30.0	7.6	25.7
Average Station Spacing (mi.)	0.22	0.47	0.50	0.56	0.54	0.20	0.73	0.84	0.78
Performance									
Ratio of Maximum to Minimum Running Time	1.03	1.30	1.42	1.19	1.25	1.05	1.12	1.14	1.28
Travel Time Reliability (Coefficient of Variation)									
Customer Perception of Reliability	65% of surveyed passengers rated Reliability Above Average or Excellent								

Exhibit 3-11: BRT Elements by System and Running Time Reliability (Continued)

	Los Angeles Metro Rapid Ventura	Los Angeles Metro Rapid Vermont	Los Angeles Metro Rapid Crenshaw	Los Angeles Metro Rapid Van Nuys	Los Angeles Metro Rapid Broadway	Los Angeles Metro Rapid Florence	Orlando LYMMO	Miami Busway Local	Miami Busway MAX
Running Way									
Mixed Flow Lanes (mi.)	16.7	11.9	18.8	21.4	10.5	10.3			
Designated Lanes (mi.)	-	-		-	-	-	-		
At-Grade Exclusive Lanes (mi.)	-	-		-	-	-	3.0	8.0	8.0
Grade-Separated Exclusive Lanes (mi.)	-	-		-	-	-	-		
ITS	-	-	-	-	-	-	-	-	-
Vehicle Prioritization									
Driver Assist and Automation	-	-		-	-	-			
Operations Mgmt.	Advanced Communication, AVL	Advanced Communication, AVL	Loop Detectors / Infrared Sensors	Advanced Communication, AVL	Advanced Communication, AVL	Advanced Communication, AVL	AVL/Wi-Fi	X	X
Service Plan	-								
Route Length	16.7	11.9	18.8	21.4	10.5	10.3	3	8	8
Average Station Spacing (mi.)	1.17	0.67	0.83	1.05	0.69	0.88	About 900 feet	0.54	1.14
Performance									
Ratio of Maximum to Minimum Running Time	1.54	1.17	1.38	1.29	1.16	1.39	1.00	1.00	1.00
Travel Time Reliability (Coefficient of Variation)									
Customer Perception of Reliability						92% of passengers rate reliability and on-time performance Excellent or Good, compared to 62% for all Lynx service			

Exhibit 3-11: BRT Elements by System and Running Time Reliability (Continued)

	Oakland Rapid San Pablo Corridor	Pittsburgh East Busway	Pittsburgh South Busway	Pittsburgh West Busway	Phoenix Rapid I-10 East	Phoenix RAPID I-10 West	Phoenix RAPID SR-51	Phoenix RAPID I-17
Running Way								
Mixed Flow Lanes (mi.)	14.0	0.4	-	0.4	6.5	4.8	12.3	8.0
Designated Lanes (mi.)		-	-	-	14.0	8.0	10.3	11.5
At-Grade Exclusive Lanes (mi.)		-	-	-	-	-	-	-
Grade-Separated Exclusive Lanes (mi.)		8.7	4.3	4.6	-	-	-	-
ITS								
Vehicle Prioritization		Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)
Driver Assist and Automation		Collision Warning	Collision Warning	Collision Warning	Collision Warning	Collision Warning	Collision Warning	Collision Warning
Operations Mgmt.					Advanced Communication, Orbital	Advanced Communication, Orbital	Advanced Communication, Orbital	Advanced Communication, Orbital
Service Plan								
Route Length	14.0	9.1	4.3	5	20.5	13	19.25	19.5
Average Station Spacing (mi.)	0.56	1.14	0.54	0.83	1.86	1.59	2.05	1.63
Performance								
Ratio of Maximum to Minimum Running Time	1.21	1.11	1.00	1.21				
Travel Time Reliability (Coefficient of Variation)		Reduced coeff. of variation of travel time from 18.8% to 10.2%			90%	100%	100%	100%
Customer Perception of Reliability				68% of passengers perceive that the West Busway has improved schedule adherence				

3.2.2 Station Dwell Time Reliability

Description of Station Dwell Time Reliability

Station dwell time reliability represents the ability for BRT vehicles to consistently load passengers within a certain dwell time and to minimize the amount of time spent at the station. Passenger loads can vary significantly throughout the day, and even within each peak period. Incorporating BRT elements to accommodate this significant variation without impacting travel times can improve reliability. This is especially important, since BRT systems serve corridors and locations with high transit demand. Lengthy dwell times can affect the overall perception of reliability beyond the actual time spent[30].

Effects of BRT Elements on Station Dwell Time Reliability

Each of the BRT element options that help make station dwell times more reliable is described below.

BRT Elements and Station Dwell Time Reliability	
Stations – Platform Height	**Level Platforms** or **Raised Curbs** facilitate consistent station dwell times by reducing the need to step up to the vehicle.
Stations – Platform Layout	**Extended Platforms** allow for more than one vehicle to board at one time and reduce the amount of time that vehicles must wait in queues to load passengers.
Vehicles – Vehicle Configuration	To comply with the Americans with Disabilities Act (ADA), a majority of vehicles being produced in the United States have low floors at the doors to facilitate boarding and alighting. Low floor vehicles not only speed boarding for general (ambulatory) passengers, they contribute to the reliability of station dwell times when integrated well with station or stop design.
Vehicles – Passenger Circulation Enhancement	In the same way that passenger circulation enhancements reduce dwell time, they also reduce dwell time variability and enhance reliability. The most dramatic of the passenger circulation enhancements that promote reliability is **Enhanced Wheelchair Securement.**
Fare Collection – Fare Collection Process	**Barrier-Enforced Pre-Payment systems** or **Proof-of-Payment Systems** eliminate the need to pay or show passes as one boards the vehicle, allowing for multiple door boarding and reducing the variability in the time it take customers to either produce the required money or the required pass.
Fare Collection – Fare Transaction Media	Electronic fare collection systems and pre-paid instruments can make dwell times more reliable primarily by reducing the need for boarding passengers to search for exact change and by reducing transaction times.

30 **The Role of Transit Amenities and Vehicle Characteristics in Building Transit Ridership,** *TCRP Report 46, Amenities in Transit, p. 27*

BRT Elements and Station Dwell Time Reliability	
ITS—Driver Assist and Automation	**Precision Docking** systems enable a BRT vehicle operator to precisely place the BRT vehicle a certain distance from the station platform to eliminate the need for wheelchair ramps.
ITS—Operations Management	**Transit Vehicle Tracking** enables a central dispatcher to know exactly where a BRT vehicle is and address problems that may arise while the BRT vehicle is at a station.
Service and Operations Plan – Service Frequency	Increasing service frequency reduces the number of passengers that can accumulate at the station, reducing the time associated with loading them.
Service and Operations Plan – Method of Schedule Control	Headway-based schedule control makes headways more regular, ensuring even loads and loading times.

Performance of Existing Systems

Research Summary

A study of boarding times for ambulatory passengers reported the times to be faster with low-floor buses, from 0.2 to 0.7 of a second. The average boarding time of wheelchair passengers was faster with the ramp than with a lift, 27.4 seconds versus 46.4 seconds. While these shorter boarding/alighting times had not resulted in increases in schedule speed at any of the transit agencies interviewed, some felt that the faster ramp operations made it easier to maintain schedule (dwell time reliability), particularly when multiple, unpredictable wheelchair boardings occurred during a run.[31]

Typical wheelchair lift cycle times including the time required to secure the wheelchair inside the vehicle are 60 to 200 seconds, while the ramps used in low-floor buses reduce the cycle times to 30 to 60 seconds. [32]

Research shows that an emerging application to reduce station dwell times is the use of rear-facing positions for wheelchair securement on transit buses. Securement of wheelchairs on transit buses can take more than 3 minutes using conventional securement devices and with the assistance of an operator.[33] Rear-facing position for wheelchairs is being

31 *King, R.,* **New Designs and Operating Experiences with Low-Floor Buses,** *TCRP Report 41, Columbus, Ohio, 1998, Executive Summary*

32 ***Transit Capacity and Quality of Service Manual****, 2nd Edition, Transportation Research Board, Washington, D.C., p. 4-3*

33 *Hardin, J. and Foreman C.,* ***Synthesis of Securement Device Options and Strategies,*** *Center for Urban Transportation Research, University of South Florida, Tampa, FL, 2002.*

incorporated into vehicles at various transit agencies in Europe and Canada, and at AC Transit in California. Sometimes, they are used in combination with more conventional forward-facing positions. A survey of six transit agencies in Canada suggests that dwell times can be less than 1 minute in cases of wheelchair loading with the use of rear-facing positions for wheelchairs.[34]

BRT Elements by System and Station Dwell Time Reliability

Exhibit 3-12 presents a summary of BRT elements that support dwell time reliability by system. Aside from vehicle configurations with low floor heights, implementation of elements to improve station dwell time reliability is rare. Low floors are incorporated into a majority of vehicle configurations. Only two systems deviate from the use of standard curbs. The South Busway in Miami-Dade County uses raised curbs while the North Las Vegas MAX uses level platforms. Use of multiple door boarding is still rare and only evident in the Orlando Lymmo (with free fares) and the North Las Vegas MAX (with barrier-free proof-of-payment fare validation).

34 *Rutenbert, U., and Hemily, B.,* **Use of Rear-Facing Position for Common Wheelchairs on Transit Buses,** *TCRP Synthesis 50, A Synthesis of Transit Practice, Transportation Research Board, 2003.*

Exhibit 3-12: BRT Elements by System and Station Dwell Time Reliability

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles	Miami	Oakland	Orlando	Pittsburgh	Phoenix
	Silver Line	Neighborhood Express	City Express!	North Las Vegas MAX	Metro Rapid	Busway	Rapid Bus	LYMMO	Busways	Rapid
Stations										
Platform Height	Standard Curb	Standard Curb	Standard Curb	Level Platform	Standard Curb	Raised Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1	3	1	2	2-3	1
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Passing Lanes at Stations			Passing Lanes at Stations	Bus Pull-Outs
Vehicles										
Vehicle Type	Stylized Articulated (60') with Low Floor	Conventional Standard (40')	Conventional Articulated (60') with Low Floor	Specialized BRT Vehicle with Low Floor	Conventional Standard (40') with Low Floor	Conventional Standard (40')	Stylized Standard with Low Floor	Conventional standard (35') with Low Floor	Conventional Standard & Articulated	Stylized Standard
Passenger Circulation Amenities				Full Low Floor						
Fare Collection										
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Proof-of-Payment	Pay On-Board	Pay On-Board	Pay On-Board	N/A (Free Fares)	Pay On-Board	Pay On-Board
Fare Media	Cash, paper swipe card	Cash & Paper, Magnetic Stripe	Cash & Paper	Cash, Magnetic Stripe	Cash & Paper	Cash & Paper	Cash & Paper	N/A	Cash & Paper	Cash, Magnetic Stripe
ITS										
Driver Assist and Automation				Precision Docking	-				Collision Warning	Collision Warning
Operations Mgmt.	Advanced Comm., Automated Dispatch, AVL	AVL	AVL	Advanced Comm., Automated Dispatch, AVL	Advanced Comm., Automated Dispatch, AVL		Automated Dispatch, AVL, Vehicle Monitoring	AVL	AVL	Automated Dispatch, AVL

3.2.3 Service Reliability

Description of Service Reliability

Service reliability is a qualitative characteristic related to the ability of a transit operation to provide service consistent with its plans and policies and the expectations of its customers. Three aspects of a transit operation that promote service reliability:

- Availability of service options– Service can be so dense and frequent that a missed or delayed trip results in little degradation of service. Passengers have multiple choices that allow them to respond to unpredictability of their own schedules and behavior (e.g., the need to work late or go home during the middle of the day).
- Ability to recover from service disruptions – Strategies to quickly respond to unpredictable delays and disruptions
- Availability of "contingency" resources – Having sufficient "back-up" permits operator to meet its service plan in the face of all the uncertainties that could affect it, e.g., driver illness, traffic, and other unforeseen events.

Effects of BRT Elements on Service Reliability

The characteristics of many BRT elements affect service reliability are discussed below.

BRT Elements and Service Reliability	
Stations – Passing Capability	Stations with passing lanes, either through **Bus Pullouts** or **Passing Lanes at Stations**, minimize the risk that delays or incidents affecting one BRT vehicle will result in delays to other vehicles along the line. Disabled vehicles can pull over to the side of the running way or a portion of the station platform, while other vehicles are able to pass and still meet their service.
Stations – Platform Layout	**Extended Platforms** allow for flexibility of operations in case any vehicle breaks down or experiences excessively long delays while loading at stations, provided that the running way through the station allows vehicles to pass.
ITS – Vehicle Prioritization Systems	Vehicle prioritization systems can help facilitate bringing a vehicle back to its scheduled position after a brief interruption or delay to service.
ITS – Operations Management	Operations Management Systems allow system managers to quickly address any incidents that may arise and disseminates that information to riders.
ITS – Passenger Information Systems	While passenger information systems do not enable greater service reliability, they allow for transit agencies and operations managers to communicate to passengers waiting for and currently using the service of any service changes or disruptions, thereby reducing the impacts of disruptions.

BRT Elements and Service Reliability

Service and Operations Plan – Service Frequency	High frequencies BRT systems (less than 5 minutes) can give passengers an impression that the service is available at any station without delay, even when headways and schedule adherence vary, as long as inordinate bunching (irregular spacing between vehicles) is avoided.
Service and Operations Plan – Service Span	Service that extends to the off-peak periods (mid-day, evening, and late night) and on weekends provides potential users with expanded options for making round trips. Expanded service spans make BRT systems dependable.

In addition to these BRT elements, an agency can improve service reliability through programs and business processes, such as:

- Enhanced maintenance programs for vehicles and other elements
- Fleet management to maintain higher spare ratios

Performance of Existing Systems

System Performance Profiles

O-Bahn Busway, Adelaide, Australia

The O-Bahn Busway in Adelaide, Australia is a 12 km guided busway system to the northeastern suburbs (opened in 1986) that uses a mechanical track guidance system developed in Germany. Buses are steered automatically using horizontal guide wheels, which engage raised concrete edges on the track. Vehicles travel at speeds of up to 100 km/hour serving three stations in the alignment. Travel times have reduced the travel time along the corridor from 40 minutes to 25 minutes.

Several aspects of the system support maximum service reliability. The stations are designed such that the vehicles pull off the guided track and serve stations that can accommodate more than one vehicle. Vehicles are, therefore, never stationary on the track. This configuration ensures that the 18 bus routes that serve the route can operate without interference due to delays on each individual route. During the peak hour, an average headway of less than 1 minute is maintained (67 vehicles per hour). Braking ability on rubber-tired vehicles also allows safe operating distances of as little as 20 seconds between vehicles along the guided track.[35] On rare cases of vehicle breakdowns on the guideway, vehicle operators inform the Traffic Control Centre and alert oncoming vehicles with a hazard light. A special maintenance and recovery vehicle, equipped with guide-wheels and able to travel in both directions is used to recover stranded vehicles and to maintain the track. While the guideway

35 *"Guiding Transport into the Future", Adelaide's O-Bahn Busway, Passenger Transport Board, December 8, 1999*

section is blocked, vehicles are diverted from the blocked section along parallel arterial streets to the next station, minimizing delays.

Tri-Met Automated Bus Dispatching, Portland, Oregon (non-BRT)

Portland's Tri-Met is a pioneer in the development, implementation, and deployment of Transit ITS systems. Its Bus Dispatch System (BDS) began implementation in 1997 and became fully operational in 1998. The main features of the BDS include: GPS based Automatic Vehicle Location; voice and data communications; an on-board computer and mobile data terminal; Automatic Passenger Counters (partial) and a Computer Aided Dispatch operations control center.

After implementation of the BDS there was noticeable improvement in both on-time performance and instances of severe bus-bunching. Overall, on-time performance increased from 61.4 to 67.2% of all trips. A 9.4% gain. The greatest improvement occurred in the AM peak period with a 129% gain. There was also a noticeable reduction in headway variation and bus bunching. Bus bunching, which is represented by headways below 70% of their scheduled values, declined by 15%. For PM Peak out-bound trips, where any irregularities in service are exasperated by the high rate of passenger arrivals causing boarding backups and delays, extreme instances of bus bunching (headway ratios < 10% of scheduled values) declined by 37% (Strathman, James, et.al., Automated Bus Dispatching, Operations Control and Service Reliability: The Initial Tri-Met Experience, Paper presented at the Year 2000 TRB Annual Conference, Washington DC, January 2000).

Regional Transit District AVL and CAD System, Denver, Colorado (Non-BRT)

The Denver Colorado Regional Transit District (RTD) was one of the first systems in the nation to install a GPS-based Automatic Vehicle Location (AVL) and Computer Aided Dispatch (CAD) system throughout its operations. The RTD transit system covers 2,400 square miles and consists of about 1,335 vehicles. These include 936 buses in fixed route service, 27 16th Street Mall buses, 175 paratransit, 17 light rail vehicles and 180 supervisor and maintenance vehicles. In 1993, the RTD began installation of an AVL system across its fleet developed by Westinghouse Wireless Solutions.

Since the AVL system was implemented the transit system has provided the customers with higher quality of service (most noticeable after final system acceptance). As reported in the US DOT evaluation, "RTD decreased the number of vehicles that arrived at stops early by 125 between 1992 and 1997. The number of vehicles that arrived at stops late decreased by 21%. These improvements are to a system that was already performing well, and outstanding considering the impact that inclement weather can have on on-time performance during winter." From 1992 to 1997, customer complaints per 100,000 boardings decreased by 26% due in large part to the improved schedule adherence.[36]

London Transport Countdown System, London England (Non-BRT)

London was one of the first cities in the world to deploy a next bus arrival system at bus stops. The system called Countdown was piloted in 1992 on Route 18 of the London system and proved highly popular with passengers. Deployment continued by stages. As of March 2002, 1473 Countdown signs had been installed and were operational. The installation of 2,400 signs was expected by March 2003, and 4,000 signs by 2005. The 4,000 signs will cover 25% of all stops and will benefit 60% of all passenger journeys.[37] While the Countdown system does not directly affect service reliability it had a noticeable impact on passenger's perceptions. It was found that 64% of those surveyed regarding the system believed service reliability had improved after Countdown was implemented.

BRT Elements by System and Service Reliability

Since the frequency of incidents and the responses to them are seldom recorded and not available in an easily comparable format, it is difficult to present a consistent measure to compare service reliability across systems. For this reason, this section characterizes performance simply by listing the BRT elements that have an effect on service reliability.

Exhibit 3-13 presents those BRT elements by systems that are most relevant to assessing the service reliability of each system.

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36 *Weatherford, M., Castle Rock Consultants,* **Assessment of the Denver Regional Transportation District's Automatic Vehicle Location System***, Volpe National Transportation Systems Center, Cambridge, MA, August 2000*

37 *Schweiger, Carol,* **Real Time Bus Arrival Information Systems, TCRP Synthesis 48***, 2003*

Exhibit 3-13: BRT Elements by System and Service Reliability

	Boston Silver Line	Chicago Neighborhood Express	Honolulu City Express!	Las Vegas North Las Vegas MAX	Los Angeles Metro Rapid	Miami Busway	Oakland Rapid Bus	Orlando LYMMO	Phoenix Rapid	Pittsburgh Busways
Stations										
Platform Length (No. of Vehicles)	1		1	1	1	3	1	2	1	2-3
Passing Capability	Adjacent Mixed Flow Lane		Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Passing Lanes at Stations			Bus Pull-Outs	Passing Lanes at Stations
ITS										
Operations Mgmt.	Advanced Communica-tion, Auto Dispatch, AVL		AVL		Advanced Communica-tion, Auto Dispatch, AVL	Auto Dispatch, Vehicle Monitoring, AVL	Automated Dispatch, AVL, Vehicle Monitoring	AVL	Automated Dispatch, AVL	AVL
Passenger Information	Station, Telephone		Station	Station, Telephone, Internet	Station, Telephone, Internet	Station, PDA, Vehicle	Station, Internet	Station, Vehicle, PDA	Station, Vehicle, PDA, Internet	
Service Plan										
Service Frequency (Peak / Off-Peak)	4	9/12	11 / 30	12/30	2-30 / 30	10 / 20	12	5/15	10 / -	12/18

3.3 IDENTITY AND IMAGE

An important objective for BRT is to establish an image and identity separate from local bus operations, to maximize the potential for attracting additional riders who might not be able to or want to use the current system. Identity here refers to "branding" and image relates to the style, aesthetics and compatibility of BRT's physical elements.

The three most visible BRT elements are the vehicles, stations, and running ways. A distinct BRT color scheme (livery) and logo used with unique, modern vehicles are growing more common in BRT systems. Most BRT systems also have stations with highly visible, distinct design cues to differentiate the BRT routes that serve them from regular local bus stops. Some combine architecture and design with high visibility to both "advertise" the system and indicate where to gain access to the BRT system.

3.3.1 Brand Identity

Description of Brand Identity

Brand identity represents how BRT system is viewed among the set of other transit and transportation options available. A BRT system may have a separate, brand identity from other parts of the transit system (e.g., local bus network) to maximize its potential to attract new riders. An identity separate from other transit services can be a successful strategy because of market differentiation as a premium service, and thus increased appeal to choice riders. In effect, BRT can establish itself as a new and distinct transit mode and enhance its competitiveness in a particular travel market with highly visible, unique design features. BRT brand identity is strengthened when the design of all BRT elements reinforce the core marketing message directed at passengers.

Effects of BRT Elements on Brand Identity

BRT Elements and Brand Identity	
Running Ways – Running Way Segregation	Just as the physical rail tracks on a rail transit line reinforce to passengers the idea that high quality rail transit service is present, running ways that have distinct identities also reinforce the idea that high quality BRT service is present. This reinforces the identity of the BRT system. The ability to impart and reinforce this system identity increases with increasing segregation.
Running Way – Differentiation	Similar to running way segregation, Running Way Markings can also supplement brand identity. Examples of differentiation techniques include pavement marking (e.g., frequent "bus only" markings on the pavement) and signs, particularly active signage (e.g., "BRT-Only") and paving running ways a unique color (e.g., maroon in Europe, Green in New Zealand, Yellow in Nagoya, Japan and Sao Paulo, Brazil). Running Way Markings "advertise" the BRT system by providing it with a distinct image and make enforcement easier when there isn't an impenetrable barrier separating the BRT-only running ways from general traffic.

BRT Elements and Brand Identity

Stations – Station Type	Perhaps no better opportunity exists to create a unique identity and theme throughout a BRT system than with station design that integrates into the local or corridor the BRT system serves. The unique identity of BRT stations creates a systemwide unified theme that is easily recognizable to customers and emphasizes BRT's unique attributes of speed and reliability. This can be accomplished with distinct architectural design that differentiates the BRT other "local" bus services. Use of **Enhanced Stops**, larger **Designated Stations**, and **Intermodal Terminals** can enhance the identity of BRT systems. Their presence advertises the presence of BRT service to potential passengers as well as providing a safe, secure, attractive and comfortable location for waiting for BRT service.
Vehicles – Vehicle Configuration	Vehicle Configurations that provide enhanced body designs – **Stylized Standard and Articulated** vehicles and **Specialized BRT Vehicles** support positive impressions of BRT systems that incorporate them. A survey of twenty-two communities planning BRT projects revealed that the high-capacity articulated vehicles were often characterized in appearance as "sleek, modern, futuristic, rail-like, speedy and new." Research shows that the "image of bus service can be significantly enhanced if the vehicles are "modern and clean." This shows that aesthetics and proper maintenance do affect passengers' perception[38]. Worldwide, the interest in modern looking, specialized BRT vehicles has led to development of several models including Irisbus' Civis in France, the Bombardier "GLT" in Belgium and France and the Berkhoff-Jonkhere Phileas in the Netherlands. Manufacturers in North America are also developing new models that incorporate aesthetics in their design.
Vehicles – Aesthetic Enhancements	Use of **Larger Windows** can reinforce brand messages of being "open" and "safe". Low-floor buses, with their high ceilings, generally have larger windows. The large windows and high ceilings provide the customer with a feeling of spaciousness, which contributes to the comfort of passengers.
Vehicles – Propulsion	Propulsion systems and fuels have clear positive effects on community integration as well as image and branding of the service. Concern for air pollution and community health effects of conventional diesel buses are important as is their noise.
Fare Collection – Fare Collection Process	Fare pre-payment allows BRT to resemble rail systems. Complete pre-payment either through **Barrier-Enforced Proof-of-Payment** or **Barrier-Free Proof-of-Payment** allows for the optimization of bus operations, thus, improving the system's image and brand identity. Fare inspectors associated with Barrier Free Proof-of-Payment Systems also provide another customer service interface. Because inspectors represent the system, there is an important balance between enforcement vigilance and an understanding customer service approach.
Fare Collection – Fare Transaction Media	Alternative fare media associate BRT systems with high technology and user-friendliness. ***Smart Cards* –** Smart cards provide quick transactions enhance the image of BRT service as a high technology and high efficiency system. Although involving significant investments, they provide tangible benefits including the possibility of

[38] **The Role of Transit Amenities and Vehicle Characteristics in Building Transit Ridership,** *TCRP Report 46, Amenities in Transit, p. 13*

BRT Elements and Brand Identity	
	auxiliary services and uses (e.g. vending machines, parking, tolls, etc.) and in creating seamless regional transit services with an integrated fare collection. ***Magnetic-Stripe Cards –*** Magnetic strip cards have many of the same benefits as smart cards although with slightly longer transactions.
ITS –Vehicle Priority, Driver Assist and Automation, Passenger Information	Including ITS elements can reinforce the association that passengers have of the particular technology with the BRT brand. **Transit Signal Priority** can be marketed as just one improvement that distinguishes a BRT service from regular bus service. **Precision Docking** is another example where the transit agency can brand the BRT service as having the ability to precisely stop at the same location each and every time. **Real-Time Traveler Information** options suggest that the system is technologically advanced enough to provide useful and timely information to customers.

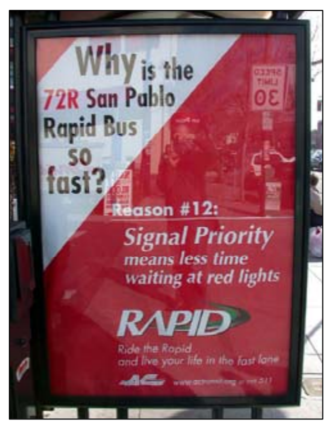
Performance of Existing Systems

System Performance Profiles

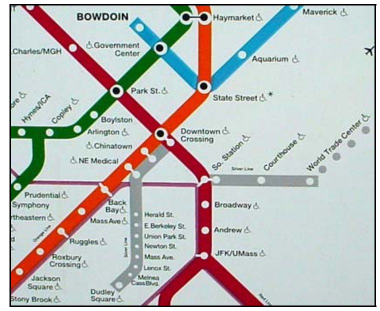
The following descriptions of branding approaches to BRT projects suggest the range of possibilities when composing a brand and assembling BRT elements to fulfill that brand identity.

San Pablo Rapid, Alameda and Contra Costa Counties, CA

The branding of the San Pablo Rapid features special designs for the vehicles and stations. The sleek state-of-the art 100 percent low-floor Van Hool vehicles dedicated to the San Pablo Rapid features the eye-catching red and white “Rapid” logo and graphics prominently on all sides of the vehicle. San Pablo Rapid stations also prominently feature the distinctive “Rapid” logo and graphics.



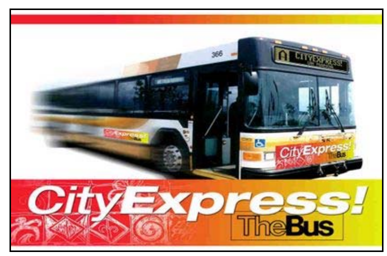
Silver Line, Boston, MA



The Silver Line bus service is branded as a new line of the MBTA's rapid transit system. The other color-coded lines on the system are heavy rail and light rail. The Silver Line is the first MBTA bus line that has been branded as rapid transit. As such, it is included in the rapid transit and route schedule of rapid transit lines. Like the rapid transit lines, but unlike all other MBTA bus lines, the Silver Line has named stops and strip maps at stops and on board vehicles. Also unlike most bus routes, a subway pass is valid on the Silver Line and a free transfer to other rapid transit lines is available for those paying cash. The silver color is used on the vehicles (which have a special Silver Line livery), stations, signs, logo, and marketing materials.

CityExpress!, Honolulu, HI

Oahu Transit Service's CityExpress! is used as a brand to identify a service type, not a specific route. There are currently two routes, A and B, that use the CityExpress! Brand that operate as a limited-stop, frequent urban system. A third route, Route C, uses the parallel CountryExpress! Brand, and operates on a highway as a commuter system. The brand is identified with a logo that is placed on buses otherwise using standard livery. (Some service is provided using 40 ft. buses, and some using 60 ft. articulated buses.) The logo is also used on signs at all stops served by this service class.



MAX, Las Vegas, NV

Due to the Las Vegas community's appreciation for advanced technology and innovative solutions, planners at the Regional Transportation Commission (RTC) of Southern Nevada developed a branding specification that highlighted all aspects of an alternative transit experience. The MAX system combined a sleek, state-of-the art vehicle, uniquely designed passenger stations, and an exclusive marketing campaign, to introduce the service and educate citizens and visitors alike regarding Bus Rapid Transit in the Las Vegas metropolitan area. The MAX vehicle features a striking, high-gloss blue, white, and gold exterior that prominently displays the MAX logo. To further brand the MAX system, the same prominent color scheme and logo are integrated into the identification of the stations, the signage, the ticket vending machines (TVM), and the overall paint scheme of the facilities. The marketing campaign employed free (Try MAX on Us) passes, MAX promotional labels on give-away bottled water, and colorful information packets. Additionally, outreach events were held throughout the community to teach riders how to use the TVMs.

Metro Rapid, Los Angeles, CA

In Los Angeles, the introduction of a unique branding specification for Metro Rapid service has been critical in getting the riding public to associate Metro Rapid with high frequency, limited stop service. In the case of Metro Rapid, the success of the program was very much predicated on Metro's service formula, which operates 4-5 minute peak hour headways on its Wilshire and Ventura lines. The riding public immediately associated Metro Rapid's distinct red buses and distinct stations with high-frequency headway-based service, and this branding strategy eased the challenge of expanding the market niche for high-frequency regional express service. Eventually the success of this branding approach prompted the Los Angeles County Metropolitan Transportation Authority to change how it branded its local service, imitating a similar design scheme for vehicles, but using a different distinct color to suggest tiers of service.

South Miami-Dade Busway, Miami-Dade County, Florida

The South Miami-Dade Busway is Miami-Dade Transit's state-of-the-art bus rapid transit system. The branding of the system is centered around the design of the system's 8.2 mile exclusive running way, which extends from the southern terminus of the rail system, Dadeland South Station. The physical presence of the busway, enables the riding public immediately identified the exclusive Busway as faster way to travel using Miami-Dade Transit. Thirty uniquely designed and painted stations are placed along the busway. Extensive landscaping along the guideway between the stations, complements the beauty of neighboring communities and adds to the system's identity. Both full-size buses and minibuses operate on the Busway and in adjacent neighborhoods, entering the exclusive lanes at major intersections. While this fleet is not designated in any special way (e.g., through a different livery or logo), the Busway Local and Busway MAX services, which operate exclusively on the busway, are operated with a designated fleet of 30-foot buses.

LYMMO, Orlando, Florida

The LYMMO is a rapid transit system that operates on a continuous loop through Downtown Orlando using gray running way pavers to denote to vehicular traffic that the lanes are only for LYMMO vehicles. The LYMMO uses smaller low-floor vehicles with colorful public-art exteriors to enhance the customer's experience and to give the system a unique identity. The LYMMO has 11 enhanced stations and 8 stops on the continuous. The stations feature shelters that are unique to the LYMMO system. In addition to these branded aspects, the LYMMO also has a unique logo that is placed on vehicles, stations, and stops. The fact that the LYMMO is free to ride and its unique branding have been important to its success as a high-frequency, fast, reliable, and premium transit service.

16th Street Mall, Denver, CO (non-BRT application)

The 16th Street Mall is a 16-block long pedestrian and transitway mall that serves as the retail core of Downtown Denver. Many features of the 16th Street Mall Transitway Denver contribute to a cohesive identity and image. The 80-foot-wide mall uses unique paving, lighting, and planting to articulate three zones of activity and give the service its identity. The first is a 22-foot-wide central promenade with mature trees that shade without blocking visibility or access to shopping. This pedestrian spine is flanked by 10-foot-wide bus paths made of the pavers (slightly depressed for safety) and expanded 19-foot sidewalks. Granite pavers of charcoal gray, light gray and Colorado red articulate the zones in a rattlesnake-like pattern that, pronounced at center, becomes less busy at the edges so as not to detract from building coloration or window displays. Specially designed lanterns light the mall for dusk, night, and after-hours security, while a wide range of new street furniture fosters a sense of coherence.

BRT Elements by System and Brand Identity

Exhibit 3-14 presents a summary of BRT elements by system for those elements that support a differentiated brand identity. The most common technique to articulate a separate brand identity is through the use of a different look for vehicles. Seven of ten systems employ a distinct livery for bus rapid transit services. Transit signal priority to improve speeds and the use of real-time passenger information at stations are two common techniques to impart an impression of high technology for bus rapid transit systems. Only two systems, Las Vegas MAX and Orlando's Lymmo use alternative fare collection processes and boarding procedures. Both use multiple door boarding (Las Vegas through the use of proof-of-payment fare collection) to simulate rail systems.

Exhibit 3-14: BRT Elements by System and Brand Identity

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Neighborhood Express	City Express!	North Las Vegas MAX	Metro Rapid
Running Way					
Mixed Flow Lanes (mi.)	0.2 miles	36.7 miles	56.6 miles	2.9 miles	115.3 miles
Designated Lanes (mi.)	2.2 miles			4.7 miles	-
At-Grade Exclusive Lanes (mi.)				-	-
Grade-Separated Exclusive Lanes (mi.)					
Guidance	-		-	Precision Docking at Stations	-
Differentiation	Striping	N/A	Concrete barriers on highway lane	Striping	N/A
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station	Enhanced Shelter
Station Access	Pedestrian Focus		Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Stylized Articulated	Conventional Standard	Conventional Standard	Specialized BRT Vehicle	Conventional Standard
Aesthetic Enhancement	Specialized Livery	Same as other Bus Services	Specialized Livery	Specialized Livery, Large Windows, Internal Bicycle Racks	Specialized Livery, Large Windows
Propulsion System	ICE - CNG	Diesel ICE	ICE – ULSD	Diesel Electric	ICE – CNG
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Proof-of-Payment	Pay On-Board
Fare Media	Cash & Paper	Cash & Paper, Magnetic Strip	Cash & Paper	Cash, Magnetic Stripe	Cash & Paper
ITS					
Vehicle Prioritization	Transit Signal Priority (2004)	-	-	Transit Signal Priority	Transit Signal Priority
Driver Assist and Automation	-	-	-	Precision Docking	-
Passenger Information	Station, Telephone	Station	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet
Performance					
Customer Perceptions of Attractiveness					
General Customer Satisfaction					

Exhibit 3-14: BRT Elements by System and Brand Identity (Continued)

	Miami Busway	Oakland Rapid Bus	Orlando LYMMO	Phoenix Rapid	Pittsburgh Busways
Running Way					
Mixed Flow Lanes (mi.)		14	-	6.5	0.4
Designated Lanes (mi.)			-	14	-
At-Grade Exclusive Lanes (mi.)	8 miles		3 miles		-
Grade-Separated Exclusive Lanes (mi.)					8.7
Guidance	-	-	-		-
Differentiation	Separate ROW	N/A	Concrete Pavers		
Stations					
Station Type	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station
Station Access	2 P&R Lots	Pedestrian Focus	Pedestrian Focus, 1 P&R Lot	1 P&R Lot	18 P&R Lots
Vehicles					
Vehicle Type	Conventional Standard and Articulated	Stylized Standard		Specialized Standard	Conventional Standard & Articulated
Styling Amenities		Specialized Livery	Specialized Livery	Specialized Livery; High-Back Seating	Standard Artic
Propulsion System	ICE – Diesel	ICE – ULSD	ICE	ICE – LNG	ICE – Diesel
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On-Board	N/A (Free Fares)	Pay On-Board	Pay On-Board
Fare Media	Cash & Paper, Magnetic Stripe	Cash & Paper	N/A	Cash, Magnetic Stripe	Cash & Paper
ITS					
Vehicle Prioritization	-	Transit Signal Priority	-	-	Transit Signal Priority (1 Signal)
Driver Assist and Automation	-	-	-	Collision Warning	Collision Warning
Passenger Information	Station, PDA, Vehicle	Station, Internet	Station, Vehicle, PDA	Station, Vehicle, PDA, Internet	Internet
Performance					
Customer Perceptions of Attractiveness	65%		93%		
General Customer Satisfaction	Average Satisfaction with Busway is 3.75 out of 5 compared to 3.61 for all MDT services	83% of riders rate Rapid Bus as Good or Excellent compared to 72% who rated the system similarly in a survey 2 years prior	Mean satisfaction: 4.41 out of 5.0; 52.5% of passengers have improved their opinions of public transit		91% of passengers surveyed indicated the West Busway was Very Important or Fairly Important in their decision to start using the bus

3.3.2 Contextual Design

Description of Contextual Design

In addition to helping establish a unique, positive identity, BRT systems should demonstrate a premium, "quality" design and be integrated with the surrounding urban communities. BRT physical elements not only serve transit customers but can serve as focal points for the communities around them. Systems where design elements are consistent and harmonize with their context provide intangible benefits to communities beyond the transportation benefits alone.

Case studies documenting integral and contextual design approaches are presented in *TCRP Report 22,* "The Role of Transit in Creating Livable Metropolitan Communities." There are detailed numerous case studies where transit stations with significant levels of amenities, irrespective of mode, have had a strong positive impact on surrounding neighborhoods and entire downtowns and other urban communities. They also provide ways for local communities to take ownership of transit service and facilities[39]. In places including Boston, Houston, Seattle, Miami and Pittsburgh, BRT and other quality bus facilities have demonstrated their ability to generate positive development and redevelopment outcomes when other factors (e.g., development market, supportive local land use policies) are present.

One major aspect of community integration is the ability of all users to access the facility, especially those with disabilities. Compliance with the requirements of the Americans with Disabilities Act (ADA) includes adequate circulation space within a bus shelter; bus stops that are connected to streets and sidewalks by an accessible path (which means that sidewalks need to be provided); and, readable signage, including bus route and schedule information.

Effects of BRT Elements on Contextual Design

BRT Elements and Contextual Design	
Running Way – Running Way Segregation	Designated running ways that are attractively designed can convey a sense of quality and permanence that potentially attracts developers and residents who desire high quality transit service. Running ways also affect the physical environment of the surrounding neighborhood. Segregation options that shield potential effects of noise and vibration can harmonize best with sensitive land uses.

[39] **The Role of Transit Amenities and Vehicle Characteristics in Building Transit Ridership,** *TCRP Report 46, Amenities in Transit, p. 26*

BRT Elements and Contextual Design	
Station – Basic Station Type	The level of attention devoted to design and architecture of BRT stations and the degree to which stations integrate with surrounding communities impacts how potential customers will perceive the BRT system and thus will have a direct impact on BRT system ridership as well as the indirect one through development changes.
Vehicle – Aesthetic Enhancement	Vehicle styling can have significant impact on the ability of the BRT system's design to fit within the context of communities. Styling that emphasizes various features such as large vehicles to simulate rail (Honolulu), sleek lines and attractive interiors (Las Vegas) and colors to suggest a high-technology theme (Boston Silver Line) can enhance the ability for BRT systems to integrate with their communities. In Boston, the combined effect has been dramatic on development in the area for both business and residential, approaching $500M to date.

Performance of Existing Systems

The nature of the design makes it inappropriate to develop a quantitative measure to summarize the relative effectiveness or success of BRT investments in achieving contextual design. This section presents system profiles of successful designs as well as a summary of system characteristics that have an effect on contextual design.

System Performance Profiles

System profiles are useful to illustrate good examples of attractive systems and successful integration of BRT systems with their surrounding communities.

LYMMO, Orlando, FL

In Orlando, the LYMMO system provides superior service on a downtown circulator route. LYMMO uses a variety of BRT elements – dedicated lanes with specialized paving, advanced computer monitoring systems, real-time bus information at stations, specially designed station shelters, and vehicles that are decorated in themes relevant to Orlando's tourism industry. Design of the stations and running way were developed in conjunction with the streetscape for downtown Orlando providing an integrated look to the system. This combination of elements have highlighted the service and have resulted in significant ridership gains by establishing a high-quality, free bus service in the downtown area. Lymmo was developed as a distinct brand with its own logo and vehicles. Free fares are also part of its appeal to the riders. After a year in operation, ridership had doubled to 91,000 in 1998.

South East Busway, Brisbane, Australia

The South East Busway in Brisbane, Australia represents an achievement in system design. The design of the system, especially, at stations, emphasizes transparency and openness through the use of generic design using clear glass and simple linear steel forms. This generic canopy and station architecture theme is carried into all stations. The openness and transparency of the design assures visibility, thereby reinforcing impressions of public safety. While the basic station form is repeated at all stations, the configuration of station architecture is tailored to specific site contexts. For example, the design and landscaping of Griffith University Station includes plantings from the nearby Toohey Forest. The landscaping at Buranda Busway Station features palm trees and other subtropical plants native to the province. The consistency of station design enables first time users and the public to gain familiarity with the stations. The simplicity of station design facilitates the movement of passengers and vehicles through the system. The design has won multiple accolades including a nomination for the Australian Engineering Excellence Awards 2001 and an Award of Commendation in the 2001 Illuminating Engineering Society State Lighting Awards.

BRT Elements by System and Contextual Design

Exhibit 3-15 presents a summary of BRT elements by system for those elements that support contextual design. The use of enhanced shelters or designated stations is the most common means to articulate a unified design in BRT systems. Often these designs are articulated to a greater degree with more exclusive running way facilities as they are with Pittsburgh's busways and Las Vegas MAX. The Metro Rapid in Los Angeles, has articulated a distinct design statement with its specially designed shelters and street furniture.

Exhibit 3-15: BRT Elements by System and Contextual Design

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Neighborhood Express	City Express!	North Las Vegas MAX	Metro Rapid
Running Way					
Mixed Flow Lanes (mi.)	0.2 miles	36.7 miles	56.6 miles	2.9 miles	115.3 miles
Designated Lanes (mi.)	2.2 miles			4.7 miles	-
At-Grade Exclusive Lanes (mi.)				-	-
Grade-Separated Exclusive Lanes (mi.)					
Guidance	-		-	Precision Docking at Stations	-
Differentiation	Striping	N/A	Concrete barriers on highway lane	Striping	N/A
Stations					
Station Type	Enhanced Shelter	Basic Stop	Enhanced Shelter	Designated Station	Enhanced Shelter
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Stylized Articulated	Conventional Standard	Conventional Standard	Specialized BRT Vehicle	Conventional Standard
Styling Amenities	Specialized Livery	Same as other Bus Services	Specialized Livery	Specialized Livery, Large Windows, Internal Bicycle Racks	Specialized Livery, Large Windows
Propulsion System		Diesel ICE	ICE – Ultra-Low Sulfur Diesel	Hybrid	ICE – CNG

Exhibit 3-15: BRT Elements by System and Contextual Design (Continued)

	Miami Busway	Oakland Rapid Bus	Orlando LYMMO	Phoenix Rapid	Pittsburgh Busways
Running Way					
Mixed Flow Lanes (mi.)		14	-	6.5	0.4
Designated Lanes (mi.)			-	14	-
At-Grade Exclusive Lanes (mi.)	8 miles		3 miles		-
Grade-Separated Exclusive Lanes (mi.)					8.7
Guidance	-	-	-		-
Differentiation	Separate ROW	N/A	Concrete Pavers	N/A	
Stations					
Station Type	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station
Station Access	2 P&R Lots	Pedestrian Focus	Pedestrian Focus, 1 P&R Lot	1 P&R Lot	18 P&R Lots
Vehicles					
Vehicle Type	Conventional Standard and Articulated	Stylized Standard		Specialized Standard	Conventional Standard & Articulated
Styling Amenities		Specialized Livery	Specialized Livery	Specialized Livery; High-Back Seating	Standard Artic
Propulsion System	ICE – Diesel	ICE – Diesel	ICE	ICE – LNG	ICE – Diesel

3.4 SAFETY AND SECURITY

Safety and security are two major attributes of transit systems. Safety is defined as the level of freedom from hazards experienced by passengers and employees of the transit system. Security is defined as the freedom from criminal or intentional danger experienced by passengers and employees. BRT systems, when properly planned, implemented, and operated can:

- Reduce accident rates
- Improve public perception of safety and security leading to increased ridership
- Improve risk management leading to reduced insurance claims, legal fees and investigations
- Reduce maintenance costs associated with damage and vandalism

The provision of a safe and secure environment for BRT customers is essential since many BRT stations and stops are likely to be unattended and open during extended hours of operation.

For the purposes of this report, safety and security are discussed separately.

3.4.1 Safety

Description of Safety

Safety is defined as the level of freedom from danger experienced by passengers and employees of the transit system. In general, two performance measures make up how well safety is managed by a transit agency:

- Accident rates
- Public perception of safety

Passenger safety can be measured in terms of actual safety accident rates per unit hour or mile of operation. These rates can be established in terms of preventable and non-preventable accidents. The public perception of safety is often measured using passenger surveys or information gathered from customer feedback.

Effects of BRT Elements on Safety

BRT Elements and Safety	
Running Way – Running Way Segregation	Running way options that involve the segregation of BRT vehicles from other traffic and from pedestrians increase the level of safety and decrease the probability and severity of collisions by BRT vehicles.

BRT Elements and Safety	
Running Way – Guidance	Guidance technologies incorporated into the running way/vehicle interface allow vehicles to follow a specified path along the running way and in approaches to stations thereby avoiding collisions while maintaining close tolerances.
Stations – Platform Height	**Raised Curbs** or **Level Platforms** reduce the possibility of tripping and facilitating wheelchair and disabled person access.
Vehicles – Vehicle Configuration	The use of vehicle configurations with partial or complete low floors may potentially reduce tripping hazards for boarding BRT vehicles. Studies performed so far, however, cannot yet point to statistically valid comparison of passenger safety for low-floor buses versus high-floor buses. In implementing low floor buses, hand holds may be necessary between the entrance and the first row of seats since, in many cases, the wheel well takes up the space immediately beyond the entrance[40].
ITS -- Driver Assist and Automation Technology	**Lane Assist** and **Precision Docking**, contribute to the safety of a BRT system through smoother operation as it is operating at high speeds, in mixed traffic or entering/exit the traffic flow.

Performance of Existing Systems

System Performance Profiles

System profiles are useful to illustrate good examples of approaches to system safety in planning for BRT systems.

South Miami-Dade Busway, Miami-Dade County , Florida

The design of traffic control is an important determinant of system safety for BRT systems. The design of traffic control at crossings is an important determinant of system safety for BRT systems. Since opening in February 1997, many serious collisions between BRT vehicles, motorists, and pedestrians have occurred at intersections along the 8.5-mile South Miami-Dade Busway. The frequency and seriousness of crashes at Busway intersections between Busway vehicles and vehicular traffic has heightened attention to Busway safety, particularly at a few intersections. Miami-Dade Transit (MDT) and Miami-Dade County have installed extensive signage and signalization to deter such crossings. MDT has also revised operating procedures, requiring that Busway vehicles proceed very slowly through Busway intersections to minimize the risk of collision. MDT has also pursued changes to the Manual of Uniform Traffic Control Devices (MUTCD) to incorporate warrants that accommodate the installation of railroad style crossing gates at intersections of BRT running ways and arterial streets.

40 *King, R.,* **New Designs and Operating Experiences with Low-Floor Buses**, *TCRP Report 41, Columbus, Ohio, 1998.*

BRT Elements by System and Safety

Exhibit 3-16 presents those elements that are most relevant to passenger and system safety by BRT system. The use of exclusive lanes in Pittsburgh has reduced the accident rates compared to operation in mixed flow traffic. Documentation of the impact of low floor vehicles and passenger injuries is not detailed enough to suggest any statistically significant relationship or contributions to reductions in tripping.

Exhibit 3-16: BRT Elements by System and Safety

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles
	Silver Line	Neighborhood Express	City Express!	North Las Vegas MAX	Metro Rapid
Running Way					
Mixed Flow Lanes (mi.)	0.2 miles	36.7 miles	56.6 miles	2.9 miles	115.3 miles
Designated Lanes (mi.)	2.2 miles			4.7 miles	-
At-Grade Exclusive Lanes (mi.)				-	-
Grade-Separated Exclusive Lanes (mi.)					
Guidance	-		-	Precision Docking at Stations	-
Differentiation	Striping	N/A	Concrete barriers on highway lane	Striping	N/A
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Level Platform	Standard Curb
Vehicles					
Vehicle Type	Stylized Articulated	Conventional Standard	Conventional Standard	Specialized BRT Vehicle	Conventional Standard
Performance					
Measured Effects on Safety					

Exhibit 3-16: BRT Elements by System and Safety (Continued)

	Miami Busway	Oakland Rapid Bus	Orlando LYMMO	Phoenix Rapid	Pittsburgh Busway
Running Way					
Mixed Flow Lanes (mi.)		14	-	6.5	0.4
Designated Lanes (mi.)			-	14	-
At-Grade Exclusive Lanes (mi.)	8 miles		3 miles		-
Grade-Separated Exclusive Lanes (mi.)					8.7
Guidance	-	-	-		-
Stations	Separate ROW				
Station Type		Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station
Platform Height	Designated Station	Standard Curb	Standard Curb	Standard Curb	Raised Curb
Vehicles	Raised Curb				
Vehicle Type	Conventional Standard and Articulated	Stylized Standard	Conventional Standard	Specialized Standard	Conventional Standard & Articulated
Performance					
Measured Effects on Safety					Bus service in East Corridor experienced a 30% reduction in all accidents but a 6% increase in passenger accidents after implementation of the East Busway

3.4.2 Security

Description of Security

The objective of passenger security is to minimize both the frequency and severity of criminal activities on impacting BRT systems. Reducing potential or perceived threats to passengers improves the image of BRT systems. Security performance measures are generally measured in terms of crime rates experienced on the transit system per unit of output (service hours or service miles). These statistics can then be compared to crime rates experienced in the system's surrounding areas or in the rest of the transit system.

These objectives of providing a secure system should be applied at all points where passengers come into contact with the BRT systems, and specifically in stations and vehicles. Fare collection systems and ITS technologies can also be central to achieving passenger security.

Effects of BRT Elements on Security

BRT Elements and Security	
Stations – Station Design	Since passengers can potentially spend time at stations in an exposed environment, designing stations to minimize exposure to crime or security threats is important. Such considerations include the provision of clear or transparent materials to preserve sightlines through the facility, incorporation of security monitoring or emergency telephones, and barriers or fare-enforcement areas to deter non-patrons from entering the station area.
Vehicles – Aesthetic Enhancement	Aesthetic Enhancements that support a secure environment emphasize visibility, brightness, transparency, and openness. Some vehicle characteristics that support these principles include **Larger Windows and Enhanced Lighting,** to promote sight lines through the vehicle. Large windows in the front and rear of the vehicle ensure there are no dim zones within the vehicle.[41]
Fare Collection – Fare Collection Process	***Proof-of-Payment*** **–**The same equipment, personnel, and procedures that are applied to collecting and enforcing fares may also be use to ensure passenger security on a system. Monitoring and surveillance measures could be applied to achieve both fare enforcement and security objectives. The presence of fare inspectors can both transmit a message of order and security and ensure a source of trained staff to assist customers in cases of emergency. ***Barrier-enforced Fare Payment*** **–** Barrier-enforced fare payment may discourage criminals from entering the system and targeting passengers with cash, provide a more secure or controlled environment for waiting passengers.

[41] *Lusk, A.,* **Bus and Bus Stop Designs Related to Perceptions of Crime**, *FTA MI-26-7004-2001.1, Executive Summary and p. 90-95*

BRT Elements and Security	
Fare Collection – Fare Media	Pre-paid instruments and passes per se may not enhance passenger security, but may be easier to control if lost or stolen and may discourage crime on the system because of the reduced number of transactions using cash. Fare media options such as contactless smart cards that allow for stored value and that do not require passengers to reveal the instrument while paying the fare may also enhance security.
ITS – Operations Management, Safety and Security Technologies	BRT security can be addressed with Operations Management technology such as Automated Scheduling and Dispatch and Vehicle Tracking. In addition, Silent Alarms and Voice and Video Monitoring are important to the security of the BRT vehicle and passengers. When criminal activity does occur, an integrated system that includes a silent alarm, video cameras and vehicle tracking can alert dispatchers instantaneously to the status of the BRT vehicle, where it is located, and what is occurring on the BRT vehicle.

Performance of Existing Systems

The level of security is difficult to quantify and measure since the motivation for promoting security is to prevent events and incidents from happening. Nevertheless, experience with incorporating security in BRT system planning suggest possible models for planning for security.

System Performance Profiles

Southeast Busway, Brisbane, Australia

The South East Busway is a two-way running way between the Brisbane CBD and Eight Mile Plains. Service continues through the Pacific Motorway to service Underwood and Springwood on the Gold Coast. It consists of elevated roadways and underground tunnels.

The South East Busway not only delivers fast and reliable bus services, it also provides a safer public transport experience. A state of the art Busway Operations Centre (BOC) at Woolloongabba plays a vital role in the management of the Busway. Among other duties, staff at the BOC monitor security at stations and detect illegal use of the Busway by unauthorized vehicles.

The entire 16.5km Busway route is covered by 140 security cameras and patrolled 24 hours a day by Busway Safety Officers (BSO). All platforms are equipped with emergency telephones which link directly to the BOC. Real-time next bus information is also provided at stations to improve trip planning by passengers.

The stations use toughened glass screens to provide open and highly transparent spaces. Stations are well lit using high lux white lighting to improve visibility and station security. Pedestrian under/overpasses make it safer to cross between platforms. Cautionary tactile paving is used throughout station entry plazas and platforms to assist the sight impaired. All stations are clearly signed, with entry plazas outlining safety tips and conditions of entry.

While there is high frequency in bus services, compared to the adjoining South East Freeway, there is relatively low volume of vehicles on the Busway. In fact, only buses and emergency vehicles are permitted to use the Busway. This lower volume makes for safer Busway operations. Buses travel at 80 km/hour on the Busway and 50 km/hr through Busway Stations (if they aren't stopping), making for a safer and more comfortable ride for passengers.

BRT Elements by System and Security

BRT elements that affect the security of each BRT system are presented in Exhibit 3-17. The Pittsburgh busways feature enhanced lighting at stations to improve security at night. Only two systems have some form of voice and video monitoring to enhance security. Boston’s Silver Line stations incorporate Emergency Telephones for communication with police.

Exhibit 3-17: BRT Elements by System and Security

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles	Miami	Oakland	Orlando	Phoenix	Pittsburgh
	Silver Line	Neighborhood Express	City Express!	North Las Vegas MAX	Metro Rapid	Busway	Rapid Bus	LYMMO	Rapid	Busways
Stations										
Station Type	Enhanced Shelter		Enhanced Shelter	Designated Station	Enhanced Shelter	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station with Enhanced Lighting
Vehicles										
Styling Amenities				Large Windows	Large Windows		Large Windows	Large Windows		
Fare Collection										
Fare Collection Process	Pay On-Board		Pay On-Board	Proof-of-Payment	Pay On-Board	Pay On-Board	Pay On-Board	N/A (Free Fares)	Pay On-Board	Pay On-Board
Fare Media	Cash & Paper		Cash & Paper	Cash, Magnetic Stripe	Cash & Paper	Cash & Paper, Magnetic Stripe	Cash & Paper	N/A	Cash, Magnetic Stripe	Cash & Paper
ITS										
Security Monitoring	Emergency Telephones			Voice and Video Monitoring				Voice and Video Monitoring		
Performance										
Measured Performance Indicators of Security										
Customer Perceptions of Security	55.6% of Passengers rated Personal safety Above Average or Excellent				Passengers rate Metro Rapid Personal Safety on Buses 3.88 out of 5, compared to 3.40 for the former Limited Bus	67.5% of passengers rate safety riding vehicles as Good or Very Good; 59.5% of passengers rate safety at Busway stations as Good or Very Good				

3.5 CAPACITY

Capacity refers to the maximum number of people or transit vehicles that can be moved past a point by a BRT line or system. In practice, there are few corridors outside the Nation's largest metropolitan areas where capacity is an issue. As the passenger demand for a particular BRT line begins to meet or exceed capacity at its critical point, it is likely to impact the quality of service: reliability tends to suffer, transit speeds decrease, and passenger loads increase[42]. Therefore, ensuring adequate capacity for BRT systems is important.

There are three key issues for BRT system capacity assessment:

- **BRT system capacity is limited by the critical link or lowest capacity element (e.g. the bottleneck) within the BRT system**—There are three key elements that determine BRT system capacity: 1) BRT Vehicle (Passenger) Capacity; 2) BRT Station (Vehicle and Passenger) Capacity, and 3) BRT Running Way (vehicle) Capacity Whichever of these is the most constraining on throughput will be the controlling factor for the entire BRT corridor.

- **There is a difference between *capacity* of a BRT system and the *demand* placed upon a BRT system**—Capacity is a measure of the estimated maximum number of passengers that *could* be served by a particular BRT line. Demand is the *actual* number of passengers utilizing the line. The volume (demand) to capacity ratio is a standard measure to determine capacity utilization.

- **Capacity is a function of the desired Level of Service (LOS) of a BRT system and vice versa** — LOS parameters effecting capacity include: 1) Availability of service (measured as frequency, span and coverage) and 2) Level of comfort (e.g., measured as standee density) 3) Travel Time 4) Reliability.

The TCRP Transit Capacity and Quality of Service Manual measures transit system capacity in person terms, the measure adopted in this report. It is defined as:

"The maximum number of passengers that can be carried along the critical section of the BRT route during a given period of time, under specified operating conditions, without unreasonable delay, hazard, or restriction and with reasonable certainty."

In presenting capacities of various BRT systems, person capacity will be expressed in terms of the theoretical maximum number of passengers that can be carried past the maximum load point along a BRT route per hour. It is important to note that the actual capacity may actually be less than the maximum person capacity due to the fact that BRT systems often operate at frequencies lower than the theoretical maximum capacity.
The remainder of this section:

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[42] **A Guidebook for Developing a Transit Performance-Measurement System,** *TCRP Report 88*

- Provides a detailed account of how BRT system capacity is calculated. (Much of the information has been distilled from the Transit Capacity and Quality of Service Manual—2nd Edition.)
- Summarizes how each BRT element affects BRT system capacity
- Provides examples of the capacity of existing BRT systems

3.5.1 Person Capacity

Description of Person Capacity

For BRT systems, the most appropriate measure of capacity is a concept called Person Capacity. Person Capacity is defined as:

> The maximum number of passengers that can be carried along the critical section of the BRT route during a given period of time, under specified operating conditions, without unreasonable delay, hazard, or restriction and with reasonable certainty.[43]

When discussing capacity, there are two key points to emphasize:

- **Capacity has multiple dimensions** – How much capacity a system is designed to accommodate or how much capacity is operated are not necessarily equal to the maximum capacity or to each other. Three dimensions are useful to consider – the maximum capacity, design capacity, and operated capacity. The differences are explained in Exhibit 3-18.

Exhibit 3-18: Different Aspects of Capacity

Dimension of Capacity	Definition	Determined by
Maximum Capacity	The unconstrained theoretical maximum capacity as determined by the physical characteristics of the system	▪ Vehicle Size (Maxium) ▪ BRT Facility
Design Capacity	Maximum capacity scaled down due to standards and policies (constraints) related to passenger comfort, safety, and manageability.	▪ Operating Policies
Operated Capacity	The capacity based on the vehicle size and frequency actually operated. The operated capacity is usually less than the maximum capacity since the operation is scaled to actual demand.	▪ Service Plan (Frequency) ▪ Vehicle Size (Actual; size may be smaller than the system can handle)

- **Demand is different from capacity.** Capacity is a measure of the estimated maximum number of passengers that *could* be served in a particular BRT system. Demand is the *actual* number of passengers attracted to use a BRT system. Certain amenities related to the accessibility of the system, such as proximity to high density development, presence of pedestrian links to stations, bicycle racks, and automobile

43 **Transit Capacity and Quality of Service Manual**, *2nd Edition, Transportation Research Board, Washington, D.C.*

parking availability may drive the demand for the BRT system, but do not define its capacity.

Effects of BRT Elements on Person Capacity

Different BRT elements determine the three different aspects of capacity described above.

Maximum Person Capacity

Three primary factors determine the maximum person capacity – Passenger Capacity of BRT Vehicles (how many passengers a vehicle can carry), the Vehicle Capacity of BRT Facilities, and Passenger Demand Characteristics. The influence of each factor on the overall system person capacity is explained in more detail below.

The **Passenger Capacity of BRT Vehicles** denotes the maximum number of seated and standing passengers that a vehicle can safely and comfortably accommodate. Other vehicle characteristics such as overall length and the number and width of doors also influence dwell times and the BRT facility capacity.

The **Vehicle Capacity of BRT Facilities** defines the number of vehicles per hour that can use a specific BRT facility. This is largely driven by characteristics and resultant capacities of the BRT system running ways and stations. For both running ways and stations, capacity is enhanced by strategies and design elements that both increase the size of the system (e.g., multiple running way lanes, larger stations) and reduce delays and improve the service rate of the system (e.g., traffic prioritization systems, access control, strategies to reduce dwell time).

Unlike other performance attributes, where the performance is determined by the sum of individual elements, capacity is determined by the most constrained element. While individual elements of a BRT system (vehicles, station loading areas, entrances to vehicles, running way lanes) have individual capacities, the BRT system capacity is determined by the bottlenecks in the system, or by the components that have the lowest person capacity. For example, there may be plenty of capacity on the running way, but if BRT vehicles back up because prior vehicles are still loading or unloading at the station, the BRT Vehicle Loading Area Capacity defines the maximum number of persons that the system can carry.

Passenger Demand Characteristics affect capacity by defining where the maximum load points (potential bottlenecks) in the system are and by affecting loading/unloading times. Key passenger demand characteristics include:

- Distribution of Passengers Over Time – The more even the distribution of passengers, the higher the system capacity.

- Passenger Trip Length – Long trip lengths decrease the number of passenger trips that can be accommodated with a given schedule.
- Distribution of Boarding Passengers Among Stations – High concentrations of passengers at stations drive the maximum dwell time which reduces the number of vehicles a system can carry.

Design Capacity

Operators often define loading and service frequency standards for various types of service and/or vehicles that are below the theoretical maximum. Examples of such standards relate to:

- **Comfort** (loading standards, standee policies) – Some premium park and ride or express service may have a policy set loading standard of no standees.
- **Safety** (minimum spacing, limits on overtaking, speed limits) – The frequency of service may be set at one vehicle every 5 or 10 minutes, even though the facility can accommodate much more frequent service based upon safe sight and stopping distances, and other traffic engineering concerns.
- **Manageability** (minimum headway, schedule recovery policies) – Operator policies may indicate stable headways can be maintained with a specific minimum headway or with provision for longer recovery time in the schedule

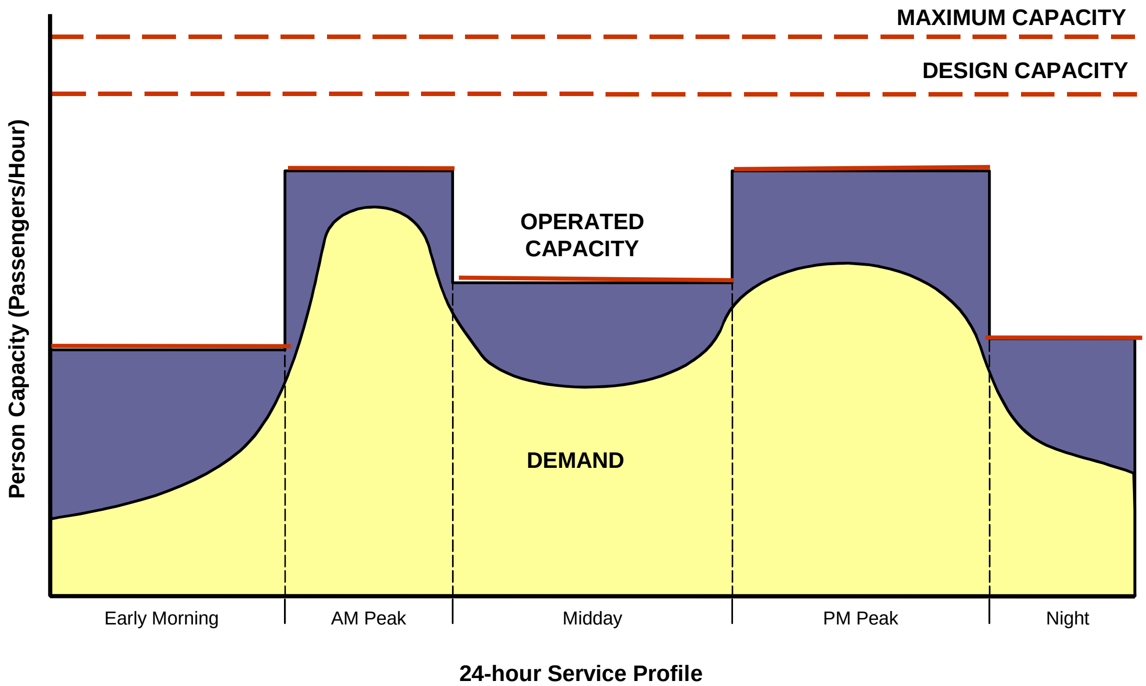
When these policy constraints are factored in, a lower "design" person capacity for the system results.

Operated Capacity

The ultimate determinant of actual capacity is the frequency of service and the size of the actual vehicles operated. Because passenger demand often does not reach the maximum capacity of the system, BRT systems operate at much lower frequency or with smaller vehicles than the system can accommodate. As demand grows, frequency and vehicle size can be increased to meet demand and take advantage of any unused capacity.

An illustration of how these various concepts of capacity relate to one another is presented in Exhibit 3-19.

Exhibit 3-19: The Relationship between Aspects of Capacity



The contribution of each BRT element to each aspect of capacity is summarized in Exhibit 3-20 and discussed in the remainder of this section.

Exhibit 3-20: Relationship of BRT Elements to Aspects of Person Capacity

Capacity Factor	Maximum Capacity			Operated Capacity – Elements Affecting What Capacity is Actually Operated
	Elements Affecting How Many Passengers Can Be Carried in a Vehicle	Elements Affecting How Many Vehicles the BRT System Can Process		
		Affect the Size of Vehicles That Can Be Accommodated	Affect How Quickly Vehicles Pass Through the System	
BRT Element				
Running Ways		●	●	
Stations		●	●	
Vehicles	●		●	●
Fare Collection			●	
ITS			●	
Service and Operations Plan				●

BRT Elements and Person Capacity

Running Ways – Running Way Segregation	Increasing the level segregation of the running way through use of **Designated Lanes, At-Grade Exclusive Lanes**, and **Grade-Separated Exclusive Lanes** reduces the number of non BRT vehicles that can use the facility and also the conflicts with parallel and crossing traffic. This increases the number and frequency of transit vehicles that each lane can accommodate. In many cases, BRT systems combine multiple types of running ways. In these cases, the running way capacity is limited by the running way section that can accommodate the lowest volume of vehicles. Effectively, the person capacity of a running way is limited by its least exclusive section.
Stations – Station Type	Factors that can influence this service time of a station (time between when a BRT vehicle enters and exits the station) include: ▪ Adequate capacity for bus bays/berths/loading areas ▪ Real-time passenger information to reduce passenger/operator interaction time (ITS) ▪ Off-board fare collection ▪ Station capacity and layout/design to allow multi-door boarding
Stations – Platform Height	**Raised Curbs** and **Level Platforms** increase capacity by facilitating the boarding and alighting process for all passengers, and are especially beneficial to the elderly, youth, and disabled passengers.
Stations – Platform Layout	**Extended Platforms** accommodate more vehicles, thereby increasing the number of passengers that can load simultaneously
Stations – Passing Capability	Stations with extra-wide running way to allow for vehicles to pass stopped, delayed, or disabled vehicles can eliminate bottlenecks in the BRT system.
Vehicles – Vehicle Configuration	Longer buses, such as **Articulated Vehicles**, have higher person capacity by as much as 50% over 40 foot buses through a combination of seated and standing passengers. The doors, floors and capacity of typical length buses are illustrated in Exhibit 3-21.
ITS – Vehicle Prioritization	Vehicle prioritization technologies – including **Signal Timing/Phasing**, **Transit Signal Priority**, **Station and Lane Access Control** – reduce conflicts with other traffic and potential delays to BRT vehicles along the running way and at station entrances and exits.
ITS – Driver Assist and Automation	Driver Assist and Automation strategies increase the potential frequency of transit service and reduce the overall time per stop. **Collision Avoidance** and **Lane Assist** allows vehicles to safely operate closer together and also allows BRT vehicles to reenter the flow of traffic more quickly and safely. **Precision Docking** will allow a BRT vehicle to precisely and consistently stop in the same location each time, speeding up the approach and departure of a vehicle from a station and reducing overall dwell time since passengers will know exactly where to line up to board.

BRT Elements and Person Capacity

ITS – Operations Management Systems	**Automated Scheduling and Dispatch Systems** allowing a higher frequency of BRT vehicles and facilitate response to incidents that create bottlenecks. **Vehicle Tracking** reduces the failure rate of BRT vehicles arriving at the BRT Station.
Service and Operations Plan – Service Frequency	Service frequency is one of the key determinants of operated capacity. Increasing frequency provides more passenger spaces in the same amount of time. Note, however, that it does not change the maximum passenger capacity of the system.
Service and Operations Plan – Operating Procedures	Other elements of Service and Operations Plans can affect the way that capacity is deployed to match passenger demand. Some elements that affect capacity are: Mandated minimum and maximum operating speeds – e.g., slowing at intersections on busways, station approach speeds ▪ Policies on standees ▪ Yield to buses when leaving stations ▪ Policies related to loading disabled passengers and bicycles ▪ Enforcement of policies prohibiting non-BRT vehicles from the running way

Exhibit 3-21: Typical U.S. and Canadian BRT Vehicle Dimensions and Capacities

Length (Feet)	Width (Feet)	# Door Channels	# Seats, including seats in wheel chair tie-down areas)	Maximum Capacity* (seated plus standing)
40 (12.2 m)	96-102 (2.45-2.6m)	2-5	35-44	50-60
45 (13.8 m)	96-102 (2.45-2.6m)	2-5	35-52	60-70
60 (18 m)	98-102 (2.5-2.6m)	4-7	31-65	80-90
80 (24 m)	98-102 (2.5-2.6m)	7-9	40-70	110-130

Capacity includes seated riders plus standees computed at a density of 3 persons per square meter.

Performance of Existing Systems

Research Summary

The capacity of BRT running ways on arterials can vary greatly based on the design and operation of running ways. A survey of running ways presented in Exhibit 3-22 of transitways around the world shows that the frequency of vehicles can reach 200 to 300 vehicles per hour.[44] This demonstrates that capacities for BRT systems can reach levels beyond the capacity needs of most developed urban corridors.

Exhibit 3-22: Maximum Observed Peak Hour Bus Flows, Capacities, and Passenger Flows at Peak Load Points on Transitways[45]

Type of Running Way	Cities Applied	Measured Peak Hour Vehicle Flows (Vehicles / Hour)	Measured Peak Hour Passenger Flow (Passengers / Hour)	Estimated Practical Capacity (Passengers / Hour)
Designated Lane	Ankara Istanbul Abidjan	91 - 197	7,300 – 19,500	5,800 – 18,100
Designated Lanes with Feeders	Curitiba, Brazil	94	9,900	13,900 – 24,100
Designated Lanes with Bus Ordering (Travelling in Clusters)	Porto Alegre (2 separate facilities)	260 - 304	17,500 – 18,300	8,200-14,700
Designated Lanes with Overlapping Routes, Passing at Stations and Express Routes	Belo Horizonte Sao Paolo	216 - 221	15,800-20,300	14,900 – 27,900

System Performance Profiles

Martin Luther King Jr. East Busway, Pittsburgh, PA

Planners at the Port Authority estimate that the Martin Luther King Jr. East Busway can accommodate one vehicle every 24 seconds or a total of 150 vehicles per hour.[46] Assuming the maximum sized vehicle that can be accommodated, an

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[44] *Gardner, G., Cornwell, P., and Cracknell, J.,* **The Performance of Busway Transit in Developing Cities,** *Transport and Road Research Laboratory Research Report 329, Department of Transport, Crowthorne, Berkshire, United Kingdom, 1991*

[45] *Gardner, G., Cornwell, P., and Cracknell, J.,* **The Performance of Busway Transit in Developing Cities**

[46] Baker, M., Jr. Inc., **Capacity Analysis and Peak Hour Loading for PATWAYS,** Rochester, PA, 1968 as cited in Pultz, S. and Koffman, D., **The Martin Luther King, Jr. East Busway in Pittsburgh, PA**, U.S. Department of Transportation, Washington, DC, 1987

articulated vehicle with 63 places[47], the maximum person capacity of the facility is 9,450 passengers per hour.

RAPID, Phoenix Public Transit Department

The experience of the Phoenix RAPID system demonstrates how the operated frequency determines the Operated Capacity of a BRT system. When the RAPID system first began operation, it operated a limited number of trips oriented toward the commute market. Furthermore, the Phoenix Public Transit Department utilized buses specially built for the commuter-type service it was operating that indicated passengers would have a comfortable high-back, reclining seat. Hence, the Phoenix Public Transit Department, through its policy of limiting standees, reduced the overall capacity of each bus to a dictated Design Capacity.

As the RAPID service continued and external events impacted potential riders (e.g., rising gas prices, pollution, and urban congestions) demand began to exceed the pre-determined Operated Capacity which left many riders as standees for numerous trips during the peak periods. While the RAPID system could have continued operating with standees, the comfort of the passengers (e.g. seat availability) was a critical element in the design of the system. Four additional trips were added during the peak periods in order to add seat availability, thus increasing Operated Capacity of the system.

BRT Elements by System and Person Capacity

Exhibit 3-23 presents a summary of characteristics of BRT elements that affect capacity and resultant capacities by system for several BRT systems. In most cases, current BRT systems in revenue operation (those shown in Exhibit 3-23) are not operating at or near their design or maximum capacity. Even for those systems which operate an integrated network, Miami and the West and South Busways in Pittsburgh, the combined headways are nowhere near the capacity of the running way. Only the East Busway hosts frequencies (at 104 vehicles during the peak hour) that come close to the maximum capacity of the facility. Therefore, the constraint on capacity is the frequency of vehicles actually operated, not the facility or infrastructure. No system has yet reached the maximum vehicle capacity of its running way.

[47] *Pultz, S. and Koffman, D.,* **The Martin Luther King, Jr. East Busway in Pittsburgh, PA**, *U.S. Department of Transportation, Washington, DC, 1987.*

Exhibit 3-23: BRT Elements by System and Person Capacity

	Boston Silver Line	Chicago Western Avenue Express (X49)	Chicago Irving Park Express (X80)	Chicago Garfield Express (X55)	Honolulu City Express A	Honolulu City Express B
Running Ways						
Mixed Flow Lanes (mi.)	0.2	18.3	9.0	9.4	19.6	7.0
Designated Lanes (mi.)	2.2					
At-Grade Exclusive Lanes (mi.)						
Grade-Separated Exclusive Lanes (mi.)						
Guidance	-	-	-	-	-	-
Stations						
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1	1
Passing Capability	Adjacent Mixed Flow Lane					
Vehicles						
Vehicle Type	Specialized BRT Vehicle	Conventional Standard (40')	Conventional Standard (40')	Conventional Standard (40')	Conventional Articulated (60')	Conventional Articulated (60')
Fare Collection						
Fare Collection Process	Pay On-Board	Pay On Board	Pay On Board	Pay On Board	Pay On-Board	Pay On-Board
ITS						
Vehicle Prioritization	Transit Signal Priority					
Operations Mgmt.	Adv. Comm., AVL				Adv. Comm., AVL	Adv. Comm., AVL
Service Plan						
Service Frequency (Peak Headway in Minutes)	4	9	12	11	11	30
Performance						
Operated Maximum Vehicles Per Peak Hour (BRT Vehicles)	15	6.5	5	5.5	5.5	2
Operated Vehicles Per Peak Hour (Non-BRT Vehicles)	-	5.5	7			

Exhibit 3-23: BRT Elements by System and Person Capacity (Continued)

	Honolulu	Las Vegas	Los Angeles	Los Angeles	Los Angeles	Los Angeles
	City Express C	North Las Vegas MAX	Metro Rapid Wilshire	Metro Rapid Ventura	Metro Rapid Vermont	Metro Rapid Crenshaw
Running Ways						
Mixed Flow Lanes (mi.)	30.0	2.9	25.7	16.7	11.9	18.8
Designated Lanes (mi.)		4.7			-	
At-Grade Exclusive Lanes (mi.)					-	
Grade-Separated Exclusive Lanes (mi.)					-	
Guidance	-	Precision Docking at Stations	-	-	-	-
Stations						
Station Type	Enhanced Shelter	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Level Platform	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1	1
Passing Capability		Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane		
Vehicles						
Vehicle Type	Conventional Articulated (60')	Specialized BRT Vehicle	Conventional Standard (40')	Standard	Standard	Standard
Fare Collection						
Fare Collection Process	Pay On-Board	Proof-of-Payment	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board
ITS						
Vehicle Prioritization		Transit Signal Priority	Transit Signal Priority			
Operations Mgmt.	Adv. Comm., AVL	Adv. Comm., AVL	Adv. Comm., AVL	Advanced Communication, AVL	Advanced Communication, AVL	Loop Detectors / Infrared Sensors
Service Plan						
Service Frequency (Peak Headway in Minutes)	30	17	9		4	13
Performance						
Operated Maximum Vehicles Per Peak Hour (BRT Vehicles)	2	4	7	15	17	4.5
Operated Vehicles Per Peak Hour (Non-BRT Vehicles)		2	3 - 9	6.5	7	4

Exhibit 3-23: BRT Elements by System and Person Capacity (Continued)

	Los Angeles Metro Rapid Van Nuys	Los Angeles Metro Rapid Broadway	Los Angeles Metro Rapid Florence	Orlando LYMMO	Miami Busway Local	Miami Busway MAX	Oakland Rapid
Running Way							
Mixed Flow Lanes (mi.)	21.4	10.5	10.3				14.0
Designated Lanes (mi.)	-	-	-	-	15	8	
At-Grade Exclusive Lanes (mi.)	-	-	-	3.0			
Grade-Separated Exclusive Lanes (mi.)	-	-	-	-			
Guidance	-	-	-	-	-	-	
Stations							
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Designated Station	Designated Station	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Raised Curb	Raised Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	2	3	3	1
Passing Capability					Passing Lanes at Stations	Bus Pullouts	
Vehicles							
Vehicle Type	Standard	Standard	Standard	Standard, Articulated, Minis	Standard, Articulated, Minis	Standard, Articulated, Minis	Stylized Standard
Fare Collection							
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	N/A (Free Fares)	Pay on Board	Pay on Board	Pay On-Board
ITS							
Vehicle Prioritization							
Operations Mgmt.	Advanced Communication, AVL	Advanced Communication, AVL	Advanced Communication, AVL	AVL/Wi-Fi	X	X	
Service Plan							
Service Frequency (Peak Headway in Minutes)	15	30	11	5	10	10	12
Performance							
Maximum Critical Link Capacity							
Operated Maximum Vehicles Per Peak Hour (BRT Vehicles)	4	2	5.5	8	4.5	12	5
Operated Vehicles Per Peak Hour (Non-BRT Vehicles)	5.5	9.5	4	-			2

Exhibit 3-23: BRT Elements by System and Person Capacity (Continued)

	Pittsburgh	Pittsburgh	Pittsburgh	Phoenix	Phoenix	Phoenix	Phoenix
	East Busway	South Busway	West Busway	Rapid I-10 East	RAPID I-10 West	RAPID SR-51	RAPID I-17
Running Way							
Mixed Flow Lanes (mi.)	0.4	-	0.4	6.5	4.8	12.3	8.0
Designated Lanes (mi.)	-	-	-	14	8.0	10.3	11.5
At-Grade Exclusive Lanes (mi.)	-	-	-		-	-	-
Grade-Separated Exclusive Lanes (mi.)	8.7	4.3	4.6		-	-	-
Guidance	8.7						
Stations							
Station Type	Designated Station	Designated Station	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	2-3	2-3	2-3	1	1	1	1
Passing Capability	Passing Lanes at Stations	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Bus Pull-Outs	Bus Pull-Outs	Bus Pull-Outs	Bus Pull-Outs
Vehicles							
Vehicle Type	Conventional Standard & Articulated	Conventional Standard & Articulated	Conventional Standard & Articulated	Specialized Standard	Specialized	Specialized	Specialized
Fare Collection							
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board
ITS							
Vehicle Prioritization	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)	Traffic Signal Priority (1 Signal)
Operations Mgmt.	AVL	AVL	AVL	Automated Dispatch, AVL	Automated Dispatch, AVL	Automated Dispatch, AVL	Automated Dispatch, AVL
Service Plan							
Service Frequency (Peak Headway in Minutes)	12 (base service); < 1 minute (all services during peak)	12 (base service)	12 (base service)	10	10	10	10
Performance							
Maximum Critical Link Capacity							
Operated Maximum Vehicles Per Peak Hour (BRT Vehicles)	104		45	6	6	6	6
Operated Vehicles Per Peak Hour (Non-BRT Vehicles)	-	-	-	-	-	-	-

4.0 BRT SYSTEM BENEFITS

The previous chapter related BRT system elements to various aspects of transit system performance. This chapter elaborates on five key benefits of implementing BRT. These benefits include three system benefits, and two community benefits:

System Benefits

Higher Ridership – The primary mission of transit service is to provide a useful service to passengers. The number of passengers is the surest indicator that a service is attractive and appropriately designed.

Cost Effectiveness is the effectiveness of a given project in achieving stated goals and objectives per unit investment

Operating Efficiency suggests how well BRT system elements support effective deployment of resources in serving transit passengers.

Community Benefits

Transit-Supportive Land Development — Transit-oriented development promotes livability and accessibility of communities, and the increases value of properties and communities surrounding transit investments.

Environmental Quality is an indicator of regional quality of life, supporting the health and well-being of the public and the attractiveness and sustainability of the urban and natural environment.

The discussion for each benefit includes four major subsections:

- a description of the benefit and how it is generated,
- an exploration on how BRT system elements and performance characteristics support the benefit,
- a discussion of other factors that affect the benefit, and
- a summary of experience in demonstrating the benefit for implemented BRT systems.

Other Benefits

Like all successful transit modes, bus rapid transit may also result in other system benefits. These benefits can include:

- Increased Revenue – Ability to generate revenue from new riders, new ways of collecting fares, or new auxiliary revenue sources (e.g., advertising opportunities on passenger information).

- Reduced Congestion – The ability to attract riders from the automobile can help reduce or limit the growth in congestion.
- Economic productivity – Improvements to BRT system design can save time for existing BRT passengers, improve mobility for new BRT passengers, and reduce congestion on the road network, saving time for automobile users and freight carriers.
- Quality of Life – Providing mobility alternatives and improving transit-supportive development can improve the quality of life of a region. Transit also supports community preservation.
- Improved Economic Opportunities – Providing additional mobility choices can enhance the pool of employment opportunities a regional population can pursue and reduce costs associated with more expensive modes. Retail establishments and other businesses benefit from increased sales and labor force availability.
- Job Creation – Transit investment has direct positive impacts on employment for the construction, planning, and design of the facilities.

These types of benefits, however, are not explored further in this chapter since

- many of these benefits are universal to all successful transit and transportation systems,
- the impacts are very specific to the context of individual transit investments,
- the impacts are difficult to separate from other factors and difficult to measure using simple system statistics.

4.1 HIGHER RIDERSHIP

4.1.1 The Benefit of Ridership

Attracting higher ridership is one of the main goals of any rapid transit investment. The ability to attract ridership reaffirms the attractiveness of the transit service and confers many benefits to a region, including reduced congestion, increased accessibility, and reduced pollution.

When considering impacts on ridership, it is important to note that BRT systems attract three types of trips:

- Existing transit trips that diverted to the new BRT system from other systems/services
- Totally new or "induced" trips that were not made before by transit or any other mode
- Trips that were previously made by another, non-transit mode (drive alone, carpool, walk or bicycle) now opt for BRT service.

BRT systems have been successful in attracting all types of trips, including existing transit users and people that previously did not use transit at all.

4.1.2 Effects of BRT Elements on Ridership

The ability of BRT service to attract higher ridership depends on how much of a comparative advantage BRT provides over other transit alternatives with respect to the key service attributes explored in Chapter 3. The impacts are discussed below.

BRT Performance and Ridership	
Travel Time Savings	Improvement in travel time (through speed improvement, delay reduction, and increases in service frequency) is the most important determinant of attracting riders to transit. To the extent that BRT reduces travel time along an existing travel corridor, net ridership may increase as a result of three effects. ▪ Improved in-vehicle travel time will attract riders who opt for BRT instead of another mode of transportation (drive, bicycle or walk). ▪ Riders of other existing transit services may be attracted to the BRT service. ▪ Improved travel time may also induce some new passengers to take a trip.
Reliability	Service reliability impacts the incurrence of unanticipated wait time or delays in travel time. Recent experience suggests that ridership response to BRT improvements is higher than would normally be expected due to travel time savings alone. Reliability may play as significant a role in attracting riders as travel time savings. Statistics on the impact of reliability on ridership are scarce due to measurement difficulties, although more data collected through the new generation of operations management tools may help to quantify the magnitude of this effect.

BRT Performance and Ridership	
Identity and Image	To the extent that the unique attributes of BRT services can be packaged in a well-designed image and identity, BRT deployment can be perceived as an enhanced transit service that caters to a niche travel market. Differentiating BRT service from other transit service is also critical to providing information as to where to access transit (e.g., stations and stops) and routing.
Safety and Security	For specific groups of potential transit riders, these safety and security considerations can override travel time savings as a factor in making the decision to take transit. BRT systems that can assure its passengers of an experience free of hazards, crimes, and security threats make passengers feel less vulnerable and more confident in choosing to start and continue using transit.

4.1.3 Other Factors Affecting Ridership

Aside from these BRT system attributes that affect ridership:

- Population Size and Characteristics – Transit systems that serve a broader service area and higher densities of passengers more prone to ride transit (e.g., households without automobiles, children, low-income groups)
- Attractiveness of Other Modes – When other modes of travel are inexpensive or convenient (e.g., parking is relative easy and inexpensive, high-speed highways are available), transit may not provide as much of an advantage.
- Linkages to other modes – The ability to link with other modes of transportation (e.g., commuter rail, inter-city rail, or pedestrian and bicycle modes) may increase the attractiveness of transit.

4.1.4 BRT Elements by System and Ridership

Ridership increases as shown in Exhibit 4-1 have been mixed. Some corridors have experienced significant ridership increases, Boston's Silver Line at 85%, and the Metro Rapid Wilshire Corridor (42%) and Ventura Corridor (27%) in Los Angeles. Much of these increases, cannot be explained by travel time savings alone. Riders appear to be attracted to a number of factors including reliability, and an articulated brand identity. Furthermore, passenger surveys are revealing that BRT systems are improving the image that choice riders have of transit. Passengers who formerly used more attractive modes, automobile travel and rapid transit, were attracted to BRT. BRT system qualities also tended to improve the impression that choice riders have of the transit system, attracting them to ride more transit.

Exhibit 4-1: BRT Elements by System and Ridership

	Boston	Chicago	Chicago	Chicago	Honolulu
	Silver Line	Western Avenue Express (X49)	Irving Park Express (X80)	Garfield Express (X55)	City Express A
Running Way					
Mixed Flow Lanes (mi.)	0.2	18.3	9.0	9.4	19.6
Designated Lanes (mi.)	2.2				
At-Grade Exclusive Lanes (mi.)					
Grade-Separated Exclusive Lanes (mi.)					
Guidance	-	-	-	-	-
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Specialized BRT Vehicle	Conventional Standard (40')	Conventional Standard (40')	Conventional Standard (40')	Conventional Articulated (60')
Styling Amenities	Specialized Livery	Same as other Bus Services	Same as other Bus Services	Same as other Bus Services	Specialized Livery
Propulsion System		Diesel ICE	Diesel ICE	Diesel ICE	ICE – Ultra-Low Sulfur Diesel
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On Board	Pay On Board	Pay On Board	Pay On-Board
Fare Media	Cash & Paper	Cash & Paper; Magnetic Stripe	Cash & Paper; Magnetic Stripe	Cash & Paper; Magnetic Stripe	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat	Flat
ITS					
Vehicle Prioritization	Transit Signal Priority (in 2004)	-	-	-	-
Driver Assist and Automation	-	-	-	-	-
Operations Mgmt.	Advanced Communication, Auto Dispatch, AVL	AVL	AVL	AVL	AVL
Passenger Information	Station, Telephone	Station	Station	Station	Station, Telephone, Internet
Service Plan					
Route Length	2.37	18.3	8.98	9.44	19.6
Route Structure	All-Stop	All-Stop	All-Stop	All-Stop	All-Stop
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Headway in Min.)	4	9	12	11	11
Performance					
Ridership					
Existing Routes (Before)	7,627		12,253 (2002)	12,728 (2002)	
Existing Routes (After)		20,310	12,065 (2004)	12,836 (2004)	
New (Additional BRT) Routes	14,105	8,518	1,122 (2004)	1,728 (2004)	
Total Ridership After BRT Implementation	14,105	28,828	13,187	14,564 (2004)	
Change in Ridership in the Corridor	85%		9% (by 2004)	14% (by 2004)	
Attractiveness to Ridership with Access to Other Modes	25.1% of Silver Line Riders used other modes before (2.5% Drive Alone, 15.1% Walk, 7.2% Not Making Trip, 1.0% Other Modes)				

Exhibit 4-1: BRT Elements by System and Ridership (Continued)

	Honolulu City Express B	Las Vegas North Las Vegas MAX	Los Angeles Metro Rapid Wilshire	Los Angeles Metro Rapid Ventura	Los Angeles Metro Rapid Vermont
Running Way					
Mixed Flow Lanes (mi.)	7.0	2.9	25.7	16.7	11.9
Designated Lanes (mi.)		4.7			-
At-Grade Exclusive Lanes (mi.)					-
Grade-Separated Exclusive Lanes (mi.)					-
Guidance	-	Precision Docking at Stations	-	-	-
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	-
Stations					
Station Type	Enhanced Shelter	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Level Platform	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Conventional Articulated (60')	Specialized BRT Vehicle	Conventional Standard (40')	Standard	Standard
Styling Amenities	Specialized Livery	Specialized Livery, Large Windows, Internal Bicycle Racks	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery, Large Windows
Propulsion System	ICE – Ultra-Low Sulfur Diesel	Diesel Electric Hybrid	ICE – CNG	ICE – CNG	ICE – CNG
Fare Collection					
Fare Collection Process	Pay On-Board	Proof-of-Payment	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	Cash & Paper	Cash, Magnetic Stripe	Cash & Paper	Cash & Paper	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat	Flat
ITS					
Vehicle Prioritization	-	Transit Signal Priority (7)	Transit Signal Priority (127 / 216)	Transit Signal Priority (88/88)	Transit Signal Priority (67/67)
Driver Assist and Automation	-	Precision Docking	-	-	-
Operations Mgmt.		Advanced Communication, AVL	Advanced Communication, Auto Dispatch, AVL	Advanced Communication, AVL	Advanced Communication, AVL
Passenger Information	Station, Telephone, Internet	Station, Telephone Internet	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet
Service Plan					
Route Length	7.0	7.6	25.7	16.7	11.9
Route Structure	All-Stop	Single Route	All-Stop	All-Stop	All-Stop
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Headway in Min.)	30	12	2		4
Performance					
Ridership					
Existing Routes (Before)			63,500	13,500	55,300
Existing Routes (After)			50,000	8,100	
New (Additional BRT) Routes	11,000		40,300	9,000	
Total Ridership After BRT Implementation			90,300 (2002) 93,094 (2004)	17,100 (2002) 19,632 (2004)	57,560 (2004)
Change in Ridership in the Corridor			42% (by 2002) 47% (by 2004)	27% (by 2002) 45% (by 2004)	4%
Attractiveness to Ridership with Access to Other Modes					

Exhibit 4-1: BRT Elements by System and Ridership (Continued)

	Los Angeles Metro Rapid Broadway	Los Angeles Metro Rapid Van Nuys	Los Angeles Metro Rapid Florence	Los Angeles Metro Rapid Crenshaw	Orlando LYMMO
Running Way					
Mixed Flow Lanes (mi.)	10.5	21.4	10.3	18.8	
Designated Lanes (mi.)	-	-	-		-
At-Grade Exclusive Lanes (mi.)	-	-	-		3.0
Grade-Separated Exclusive Lanes (mi.)	-	-	-		-
Guidance	-	-	-	-	-
Passing Capability	-	-	-		-
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	2
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Standard	Standard	Standard	Standard	Standard, Articulated, Minis
Styling Amenities	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery
Propulsion System	ICE – CNG	ICE – CNG	ICE – CNG	ICE – CNG	
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board	N/A (Free Fares)
Fare Media	Cash & Paper	Cash & Paper	Cash & Paper	Cash & Paper	N/A
Fare Structure	Flat	Flat	Flat	Flat	Free
ITS					
Vehicle Prioritization	Transit Signal Priority (75/76)	Transit Signal Priority (100/100)	Transit Signal Priority (21/60)	Transit Signal Priority (98/112)	-
Driver Assist and Automation	-	-	-	-	-
Operations Mgmt.	Advanced Communication, AVL	Advanced Communication, AVL	Advanced Communication, AVL	Loop Detectors / Infrared Sensors	AVL/Wi-Fi
Passenger Information	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet	Station, Internet
Service Plan					
Route Length	10.5	21.4	10.3	18.8	3
Route Structure	All-Stop	All-Stop	All-Stop	All-Stop	All-Stop
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak / Off-Peak)	30	15	11	13	5
Performance					
Ridership					
Existing Routes (Before)	25,900	18,800	21,700	20,600	1,750
Existing Routes (After)					--
New (Additional BRT) Routes					5,000
Total Ridership After BRT Implementation	27,762	19,192	25,439	21,265	5,000
Change in Ridership in the Corridor	7%	2%	17%	3%	186%
Attractiveness to Ridership with Access to Other Modes					1,750

Exhibit 4-1: BRT Elements by System and Ridership (Continued)

	Miami Busway MAX	Oakland San Pablo Rapid Bus	Pittsburgh East Busway	Pittsburgh South Busway
Running Way				
Mixed Flow Lanes (mi.)		14.0	10.5	10.3
Designated Lanes (mi.)		-	-	-
At-Grade Exclusive Lanes (mi.)	8	-	-	-
Grade-Separated Exclusive Lanes (mi.)		-	-	-
Guidance	-	-	-	-
Passing Capability	Bus Pullouts	-	-	-
Stations				
Station Type	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	3	1	1	1
Station Access	2 P&R Lots	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles				
Vehicle Type	Standard, Articulated, Minis	Stylized Standard (40.5')	Standard	Standard
Styling Amenities		Red, White and Green Livery	Specialized Livery, Large Windows	Specialized Livery, Large Windows
Propulsion System	ICE – Diesel	ICE – CNG	ICE – CNG	ICE – CNG
Fare Collection				
Fare Collection Process	Pay on Board	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	Cash, paper swipe card	Cash & Paper, Smart Cards	Cash & Paper	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat
ITS				
Vehicle Prioritization	Transit Signal Priority	Transit Signal Priority	Transit Signal Priority (1 intersection)	Transit Signal Priority (1 intersection)
Driver Assist and Automation	-	-	Collision Warning	Collision Warning
Operations Mgmt.	Advanced Communication, AVL	Advanced Communication, Auto Dispatch, AVL	Advanced Communication, AVL	Advanced Communication, AVL
Passenger Information	Station, PDA, Vehicle	Station, PDA, Vehicle	Station, Telephone, Internet	Station, Telephone, Internet
Service Plan				
Route Length	8	14.0	10.5	10.3
Route Structure	All-Stop, Limited, Express	All-Stop	All-Stop	All-Stop
Service Span	All Day	All Day	All Day	All Day
Service Frequency (Peak / Off-Peak)	10	12	30	11
Performance				
Ridership				
Existing Routes (Before)		12,886		
Existing Routes (After)	--	7,916 (2004)		
New (Additional BRT) Routes	9,395 (2003)	5,899 (2004)		
Total Ridership After BRT Implementation	9,395	13,815	30,000	13,000
Change in Ridership in the Corridor		7%		
Attractiveness to Ridership with Access to Other Modes		45% of Rapid passengers did not use the bus prior to Rapid Bus (19% drove by car, 13% took Bay Area Rapid Transit(BART))	11% of new riders previously used an automobile, 7% of new riders on existing routes diverted to the busway previously used a car, as compared to 1% of new riders systemwide	

Exhibit 4-1: BRT Elements by System and Ridership (Continued)

	Pittsburgh West Busway	Phoenix Rapid I-10 East	Phoenix RAPID I-10 West	Phoenix RAPID SR-51	Phoenix RAPID I-17
Running Way					
Mixed Flow Lanes (mi.)		6.5	4.8	12.3	8.0
Designated Lanes (mi.)	-	14.0	8.0	10.3	11.5
At-Grade Exclusive Lanes (mi.)	3.0	-	-	-	-
Grade-Separated Exclusive Lanes (mi.)	-	-	-	-	-
Guidance	-	-			
Passing Capability	-	Bus pullouts	Bus pullouts	Bus pullouts	Bus pullouts
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	2	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Standard, Articulated, Minis	Specialized	Specialized	Specialized	Specialized
Styling Amenities	Specialized Livery	Composite and styling	Composite and styling	Composite and styling	Composite and styling
Propulsion System	Diesel	LNG	LNG	LNG	LNG
Fare Collection					
Fare Collection Process	N/A (Free Fares)	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	N/A	Cash, Mag	Cash, Mag	Cash, Mag	Cash, Mag
Fare Structure	Free	Diff	Diff	Diff	Diff
ITS					
Vehicle Prioritization		1/1	1/1	1/1	1/1
Driver Assist and Automation	-	Collision Warning	Collision Warning	Collision Warning	Collision Warning
Operations Mgmt.	AVL/Wi-Fi	Advanced Communication, AVL/Orbital	Advanced Communication, AVL/Orbital	Advanced Communication, AVL/Orbital	Advanced Communication, AVL/Orbital
Passenger Information	Station, Internet	Station, Internet Vehicle, PDA	Station, Internet Vehicle, PDA	Station, Internet Vehicle, PDA	Station, Internet Vehicle, PDA
Service Plan					
Route Length	3	20.5	13	19.25	19.5
Route Structure	All-Stop	Express	Express	Express	Express
Service Span	All Day	Weekday Peak Hour Only	Weekday Peak Hour Only	Weekday Peak Hour Only	Weekday Peak Hour Only
Service Frequency (Peak / Off-Peak)	5	10	10	10	10
Performance					
Ridership					
Existing Routes (Before)	3,700				
Existing Routes (After)	3,300 (2003)				
New (Additional BRT) Routes	5,400 (2003)				
Total Ridership After BRT Implementation	8,700 (2003)	607 (2004)	435 (2004)	533 (2004)	797 (2004)
Change in Ridership in the Corridor	135% (by 2003)				
Attractiveness to Ridership with Access to Other Modes	34% of surveyed passengers used an automobile before using Busway services				

4.2 CAPITAL COST EFFECTIVENESS

4.2.1 The Benefit of Capital Cost Effectiveness

The primary advantage of BRT technology is that it can be adapted to a multitude of operating environments, with sufficient scalability to deliver increased carrying capacity to meet future ridership growth. The challenge in designing a new BRT system is to select a mix of elements whose associated capital costs can be reasonably justified according to expected service output levels and ridership. Often, the parameters of the BRT system are defined by physical constraints. For example, the absence of available right-of-way may preclude the feasibility of exclusive BRT running ways and designated stations. Likewise, the presence of an underutilized transportation asset may inspire the identification of BRT as a cost effective transportation solution. The point is, capital costs of new BRT systems are impacted not just by the choice of operational and design elements, but also by the physical environment within which BRT is integrated.

BRT capital cost can therefore vary greatly, depending on the mix of operational and customer interface elements that are chosen for a given BRT deployment. Chapter 2 provided a general description of the range of capital costs associated with each of the major BRT elements, and the options within each element. While information on specific elements like the capital cost per BRT station is useful, it does not, by itself, yield enough information from a planning perspective to guide the determination of specific BRT elements, such as the level of station treatments. To provide some useful planning guidance, the impacts of BRT system elements must be considered together and capital costs must be expressed in terms of system performance.

Cost effectiveness can be defined as the cost per unit of service output. Evaluation of the capital cost effectiveness of BRT projects can be performed with respect to:

- service outputs – vehicle service miles (VSM) and vehicle service hours (VSH)
- performance improvements – travel time savings, reliability improvements, safety and security improvements
- user benefits – passenger trips, cumulative travel time saved, passenger miles
- facility size – miles of investment, vehicle fleet size

4.2.2 BRT System Design Impacts on Capital Cost Effectiveness

The basic elements of BRT are discussed in Chapter 2. Within each element, treatment alternatives and their associated capital costs and associated performance vary greatly. The decision to implement a particular BRT element rests on an analysis of the costs and performance benefits of each element when applied in a specific corridor context. Standards of service such as wait time, travel time, reliability often drive the decision to pursue implementation of BRT elements. Considerations related to individual BRT elements are presented.

- *Running ways* – The driving capital cost of running ways is related to the level of separation from other traffic allowed. The least costly running way option is the mixed flow lane with the possible addition of queue jumpers. This solution does not involve any ROW acquisition or significant road construction and pavement re-striping. With increasing segregation, costs, requirements for cooperation with other stakeholders, and environmental mitigation efforts increase. The designated arterial lane, which requires improved signage, pavement re-striping and installation of physical barriers, costs between $2.5 and $2.9 million per mile (excluding ROW acquisition). The most expensive running way options are exclusive lanes, which can be either at-grade or grade-separated. While these options offer significant potential for speed and reliability, they cost between three to twenty times more than designated arterial lanes.

- *Stations* – The cost is largely driven by the size of the station, which in turn is driven by the number and frequency of routes serving the station. Stations have many community benefits that hard to quantify, yet important to consider during any cost/benefit analysis.

- *Vehicles* – Cost increases with the complexity of the vehicle configuration, the addition of enhancements, and the sophistication of the propulsion system. Specialized BRT vehicles cost the most. Their cost requires significant ridership increases, travel time benefits, and other system benefits to achieve capital cost effectiveness.

- *Fare Collection System* – Since fare collection systems for BRT are strongly integrated with the business processes and revenue collection needs of entire transit agencies, fare collection system cost effectiveness assessments often consider systemwide needs and benefits.

- *ITS* – The role of ITS is often to facilitate and improve the management and performance of other elements and systems. Their performance, therefore, is linked to how well these technologies improve performance in conjunction with other elements such as running ways and vehicles. Like fare collection systems, ITS often requires systemwide application to be justified. Systemwide benefits of application are relevant for analyses of capital cost effectiveness.

4.2.3 Other Factors Affecting Capital Cost Effectiveness

Several external factors affect capital cost effectivensss:

- Labor and Materials Costs – The strength of the local economy will determine the relative cost of labor and materials and will create regional differences in the costs to develop BRT systems.

- Real Estate Costs – Because running ways and stations comprise some of the larger expenses in developing BRT, they play a large role in the ability to develop cost-effective BRT solutions. Regions where right-of-way and property are very expensive will demonstrate higher cost systems.

- Performance of the Transportation System – The performance of the existing transportation system drives how much a benefit a new BRT system investment can bring. Introducing a superior BRT system into a environment with a highly congested transportation system or a low-speed, unreliable transit system can reap significant benefits to justify an investment.

4.2.4 Summary of Impacts on Capital Cost Effectiveness

System Performance Profiles

Several cases demonstrate the determinants of capital cost effectiveness.

South Miami-Dade Busway, Miami, FL; LYMMO, Orlando, FL

BRT capital costs vary considerably, depending on the type of system ultimately designed and built. Costs of BRT projects can include the cost of the running way, stations/stops, ITS components such as signal priority and real-time information systems, and vehicles, if additional or special buses are needed for the BRT system. The total capital cost for the LYMMO BRT in Orlando, Florida was $21 million, or $7 million per route mile. The LYMMO BRT operates on dedicated running way for the entire length of its 3.0 mile route. The total capital cost for Phase I of the South Miami-Dade Busway was 42.9 million with $17 million going to the purchase of dedicated right-of-way to build the actual busway on which buses travel separate from vehicular traffic. This comes out to about $5.0 million per mile in capital costs to build Phase I of the project.

98-B Line, Vancouver, British Columbia, Canada

The reduced travel times and the improved reliability of the 98-B Line BRT system in Vancouver have enabled a 20 percent reduction of the vehicle fleet for an equivalent transit demand, or approximately 5 vehicles. The vehicle capital cost saving from reduced layover time associated with AVL and transit signal priority (TSP) systems is estimated to result in savings of one additional vehicle. Translink (the transit operator) calculates that significant savings will accrue due to fewer vehicles, fewer vehicle hours, and higher transit revenue. Using costs (vehicles, stations, infrastructure, land, AVL/TSP, maintenance facility, soft costs, and operating costs) and benefits (operating savings, increased revenues, travel time savings) calculated in Canadian dollars, local planners estimate the benefit/cost ratio at 1.3.[45]

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45 *"98 B-Line Bus Rapid Transit Evaluation Study", IBI and Translink, September 29, 2003*

4.3 OPERATING COST EFFICIENCY

4.3.1 The Benefit of Operating Efficiency

Operating efficiency can be defined as the ability to produce a unit of service output from a unit of input. The operating efficiency of a BRT system is influenced by the interplay of several critical factors: the packaging of BRT elements, the design and implementation of service and operating plans, and the size of the BRT market. As mentioned previously, one of the distinguishing attributes of BRT is its adaptability into an existing transit network, and the ability to achieve high levels of operational efficiency at relatively low capital costs. Planning and designing a BRT system requires careful consideration of the trade-off between capital costs and operating efficiency, which is not a simple task.

The purpose of this section is to identify the impact of BRT system design elements on operating efficiency. To do this, it is useful to define how operating efficiency is measured and to define key performance indicators that can be used to monitor operating efficiency and productivity. In transit, there are several dimensions that – taken together – provide a well-rounded and balanced perspective of system performance. Operating cost efficiency is generally defined as the operating cost per unit of service output. Another important performance indicator is service productivity, which measures how much service is consumed (passengers or passenger miles) per unit of service output.

Measures of operating efficiency and productivity applied to BRT are common to the transit industry, to enable a comparison between BRT and other local fixed route service, and among BRT systems nationally. Examples of performance indicators used as part of an ongoing performance measurement system include:

- Subsidy per passenger mile
- Subsidy per passenger
- Operating cost per passenger
- Operating cost per vehicle service mile (VSM)
- Operating cost per vehicle service hour (VSH)
- Passengers per VSH
- Passengers per VSM
- VSH per Full-Time Equivalent Employee (FTE)

Operating efficiency can also be measured in terms of dimensions of service quality. For example, BRT systems that operate on exclusive running ways and have stations with level platform boarding realize operating efficiencies that cannot be achieved by BRT systems that operate along mixed flow lanes with uneven platform boarding. In the latter BRT deployment scenario, running times are less reliable, station dwell times tend to be longer and end-to-end travel times tend to be longer. To compensate for high variation in system performance, the BRT operating and service plan may involve increased service frequency levels – especially in the AM and PM peaks – specifically to mitigate schedule adherence problems. In this case, operating inefficiencies result in service input requirements that are higher than would otherwise be needed.

Section 4.5.2 presents a summary of performance in operating efficiency for BRT systems in the United States.

4.3.2 Summary of Impacts on Operating Efficiency

System Performance Profiles

Several cases demonstrate the determinants of operating efficiency.

Metro Rapid Wilshire - Whittier, Los Angeles, CA

The Metro Rapid Wilshire – Whittier line in Los Angeles, CA operates in the highest density transit corridor in the region. Before the implementation of Metro Rapid, a combination of 7 local and limited service lines operated in the corridor (five in the Wilshire Boulevard corridor and 2 in the Whittier Boulevard corridor). In terms of service effectiveness and efficiency variables, Metro Rapid improved the performance of transit service in the corridor, as shown in Exhibit 4-2.

Exhibit 4-2: Operating Efficiencies in the Wilshire – Whittier Metro Rapid Corridor

	Passengers per Revenue Hour		Subsidy Per Passenger Mile		Subsidy Per Passenger	
Route	Before Metro Rapid	After Metro Rapid	Before Metro Rapid	After Metro Rapid	Before Metro Rapid	After Metro Rapid
18 / 318*	62	63	$0.17	$0.18	$0.51	$0.46
20 / 21 / 22 / 320* / 322*	43	61	$0.21	$0.15	$1.08	$0.58
Metro Rapid 720		57.2		$0.14		$0.82
Combined	51	59.7	$0.20	$0.15	$0.79	$0.65

* Cancelled after implementation of Metro Rapid

Metro Rapid's implementation increased the service productivity from 51 passengers per vehicle revenue hour to 59.7 passengers per vehicle revenue hour. It also reduced corridor subsidies related to both passenger miles and total passengers. Note that operating efficiencies for the Metro Rapid service in both passengers per revenue hour and subsidy per passenger are higher than for the local lines. The benefit of Metro Rapid is that it improved performance measures for the corridor transit service as a whole.[46]

South Miami-Dade Busway, Miami, FL; LYMMO, Orlando, FL

Operating costs for BRT systems included such costs as driver's salaries, fuel, vehicle maintenance, and maintenance of physical facilities such as stations and running ways. In Miami, Metro-Dade Transit (MDT) uses smaller 30-foot buses on the Busway to keep operating costs to a minimum. The use of the smaller mini-buses has greatly reduced the operating cost per revenue hour of busway operation. The annual operating cost for the LYMMO in Downtown Orlando is approximately $1 million.

West Busway, Pittsburgh, PA

The West Busway in Pittsburgh demonstrated the following performance measures for operating cost efficiency and cost effectiveness as illustrated in Exhibit 4-3 and Exhibit 4-4:[47]

Exhibit 4-3: Performance Measure of Operating Cost Efficiency (Vehicle Miles per Vehicle Hour)

Operating Cost Per	
Vehicle Revenue Mile	$6.40
Vehicle Revenue Hour	$81.90
Passenger Mile	$0.65
Unlinked Passenger Trip	$2.73

Martin Luther King Jr. East Busway, Pittsburgh, PA

The speed of the East Busway allows more vehicle miles of service to be operated with the same number of vehicle hours, which drive major operating costs such as labor costs.

[46] *Transportation Management & Design, Inc.,* **Final Report, Los Angeles Metro Rapid Demonstration Program**, *Los Angeles County Metropolitan Transportation Authority and the Los Angeles Department of Transportation, Los Angeles, CA, March 2002*

[47] **Bus Rapid Transit Evaluation of Port Authority of Allegheny County's West Busway Bus Rapid Transit Project**, *U.S. Department of Transportation, Washington, DC, April 2003*

Exhibit 4-4: Performance Measure of Operating Efficiency (Vehicle Miles per Vehicle Hour)

Route Type	Vehicle Miles per Vehicle Hour
New routes	15.8
Routes diverted to East Busway	19.6
Other Routes in System	11.5

The comparison of vehicle miles per vehicle hour shows that routes on the East Busway are able to generate between 37 and 70 percent more vehicle miles from each vehicle hour.[48] An analysis performed by Port Authority Transit (now Port Authority of Allegheny County) assigned operating costs to transit trips and calculated operating cost parameters for different types of routes.

Exhibit 4-5: Operating Cost per Service Unit By Type of Route

(1983 Dollars)

Performance Measure	Ridership	New Routes	Diverted Routes	All Other Routes in System
Cost Effectiveness	Per Passenger Trip	$0.76	$1.95	$1.27
	Per Peak Passenger Trip	$1.32	$3.19	$3.09
	Per Passenger Mile	$0.15	$0.37	$0.24
	Per Peak Passenger Mile	$0.27	$0.60	$0.58
Cost Efficiency	Per Seat Mile	$0.06	$0.06	$0.07
	Per Peak Seat Mile	$0.12	$0.09	$0.16
	Per Vehicle Mile	$3.61	$2.58	$3.26

The analysis shows that new routes and diverted routes on the busway operate with higher operating efficiencies with respect to capacity operated (seat mile and peak seat mile). Diverted routes have lower operating costs per vehicle mile than other non-busway routes. (The higher cost of operating vehicle miles for new routes can be attributed to the fact that those routes are operated with articulated vehicles). Furthermore, new routes have higher cost effectiveness, with lower costs per unit of service consumed across the board, especially since demand is close to the operated capacity. Diverted routes demonstrate lower cost effectiveness since they tend to generate demand further below capacity than other routes.[49]

48 *Pultz, S. and Koffman, D.,* ***The Martin Luther King, Jr. East Busway in Pittsburgh, PA****, U.S. Department of Transportation, Washington, DC, 1987*

49 *Barton-Aschman, "Methodology Used in the Fare Structure Study,"* ***PAT Technical Memorandum****, March 1982, as cited in Pultz, S. and Koffman, D.,* **The Martin Luther King, Jr. East Busway in Pittsburgh, PA**, *U.S. Department of Transportation, Washington, DC, 1987*

4.4 TRANSIT-SUPPORTIVE LAND DEVELOPMENT

4.4.1 The Benefit of Transit-Supportive Land Development

Like other forms of high-capacity, high-quality transit, BRT has a potential to promote transit-supportive land development – promoting greater accessibility and employment and economic opportunities by concentrating development, increasing in property values, and creating more livable places. BRT corridors serve both existing land use and have the ability to create new land forms along the transit system.

Investment in public transit facilities such as stations or other transit infrastructure can create a net economic regional impact as well as a direct net impact for transit system customers by allowing increased access to jobs and other services as well as improved mobility. Supported by a steady stream of pedestrians and transit customers, a mix of employment, retail and leisure activities are developing around BRT stations. In many BRT systems, transit-oriented development is being used as a tool to encourage business growth, to revitalize aging downtowns and declining urban neighborhoods, and to enhance tax revenues for local jurisdictions.

It is important to note that the economic benefits of transit-supportive land development generally can be classified into three categories[50]:

- Generative impacts - produce net economic growth and benefits in a region such as travel time savings, increased employment and income, improved environmental quality, and increased job accessibility. This is the only type of impact that results in a net economic gain to society at large.
- Redistributive impacts - account for locational shifts in economic activity within a region such that land development, employment, and, therefore, income occur at transit stations along a route, rather than being dispersed throughout a region.
- Transfer impacts - involve the conveyance or transfer of moneys from one entity to another such as the employment stimulated by the construction and operation of a transit system financed through public funds, joint development income, and property tax income from development redistributed to a transit corridor through station development.

For example, an analysis of development around BRT stations in Ottawa, Canada (the Transitway system) found new development having an aggregate value of over $675 million (US$) had been constructed in the first 15 years after the transitway system was constructed. A similar study by the MBTA indicates $700 million in new development and construction around Silver Line BRT stations to date. In addition, a report indicates that residential properties within walking distance of stations on Brisbane's SE Busway in

[50] **Economic Impact Analysis of Transit Investments: Guidebook for Practitioners,** *TCRP Report 35*

Australia have increased in value 20 percent faster than properties in the same corridor that are not in walking distance.

Between 1983 when it opened and 1995, there was over $300m worth of construction adjacent to stations on the Martin Luther King or East Busway in Pittsburgh, despite only modest economic gains elsewhere in the Pittsburgh Region.

4.4.2 BRT System Design Effects on Transit-Supportive Land Development

Specific design elements of a BRT system, particularly those that involve physical infrastructure investment each have positive affects on land use and development.

BRT Elements and Transit-Supportive Land Development	
Running Way	Research shows that the effect of investments in running ways is three-fold. ▪ They improve the convenience of accessing other parts of a region from station locations. ▪ Increased accessibility increases the likelihood that property can be developed or redeveloped to a more valuable and more intense use. ▪ Physical running way investments signal to developers that a local government is willing to invest in a significant transit investment and suggest a permanence that attracts private investment in development.
Stations	Station design has the greatest impact on the economic vitality of an area. A new BRT station provides opportunity to enhance travel and create a livable community at the same time. Station designs that effectively link transit service to the adjacent land uses maximize the development potential. It is important to note that the inclusion of routes in BRT systems that combine feeder service and line-haul (trunk) service reduces the need for large parking lots and parking structures, thereby freeing land at the most accessible locations for development.
Vehicles	Vehicles can reinforce attractiveness (and, indirectly, the development potential) of BRT-adjacent properties to the extent that they: ▪ Demonstrate attractive aesthetic design and support brand identity of the BRT system ▪ Suggest permanence or a willingness on the part of the public sector to invest in the community ▪ Reduce negative environmental impacts such as pollutant emissions and noise. Experience in Boston and Las Vegas suggests that developers do respond to services that incorporate vehicles that are attractive and that limit air pollutant and noise emissions. Successful developments in Pittsburgh and Ottawa, Canada, where more conventionally designed vehicles are deployed suggests that development can still occur with all vehicle types as long as service improvements highlight the attractiveness of station locations.
Service and Operations Plan	The flexible nature and high frequencies of BRT service plans allows it to expand or contract with changes in land use quickly and easily.

4.4.3 Other Factors Affecting Transit-Supportive Land Development

Policy and Planning

In most cases, transit agencies in the United States do not have direct authority to plan or direct the development patterns of areas around stations of its system. Land development policy and planning instruments, such as plans and zoning codes, determine several characteristics that affect development:

- Land use intensity
- Mix and variety of uses
- Guidelines for site planning, architecture, pathways, and open spaces that affect the pedestrian-oriented nature of an area
- Parking Requirements

Transit agencies often support standards that increase the transit market base – density bonuses, promotion of land use mixing, removal or relaxation of density caps, removal of height limits, reduction of parking ratios.

Economic Environment

Transportation is a necessary condition for development but does not drive development. The rate of regional development is defined by the strength of the local economy. In addition to BRT system characteristics and local planning and zoning, the local economy drives how much development can occur. While the local economy is largely out of the control of transit agencies, agencies sometimes play a role in directly supporting development projects.

4.4.4 Summary of Transit-Supportive Land Development Impacts

System Performance Profiles

Several projects illustrate the synergy between BRT systems and transit-supportive development.

Silver Line, Boston, MA

Phase I of the Silver Line was developed along the Washington Street corridor, which emanates to the southwest from downtown Boston. The Washington Street corridor is historically a strong corridor for development owing to its history as the primary link between downtown Boston and towns to the south and west. An elevated heavy rail line which ran down the center of Washington Street was relocated in the 1987, to new track and stations along the Southwest Corridor from Forest Hills to downtown Boston. This FTA-funded project arose from the Boston Transportation Planning Review of 1972, which called for the planned interstate highway along the Southwest Corridor to be cancelled, and to use the already cleared right-of-way for transit and parks instead. Removing both elevated highways and elevated rail in urban areas was seen as a desirable improvement. In the Dudley to Downtown corridor, the Orange Line stations were relocated approximately five blocks northwest of Washington Street.

Removing the elevated, repaving the roadway, and improving the streetscape were seen as key elements to the revitalization of Washington Street, which has been severely depressed throughout the 1970s and 1980s and had seen derelict, abandoned, and demolished structures. Throughout the planning and construction of the Silver Line Phase I project, development has accelerated along the corridor, resulting in at least $93 million in new development. Projects includes a mix of retail, housing, and institutional uses, including police stations and medical facilities. Most projects include retail on the ground level.

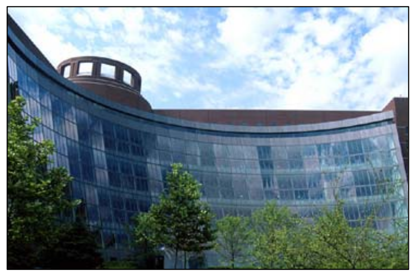
Phase II of the Silver Line (also known as the South Boston Piers Transitway) consists of an underground bus tunnel (planned to open late 2004) beginning at South Station, which is also served by the Red Line subway, commuter rail, Amtrak, and inter-city buses. This facility was conceived as a way to enable the expansion of downtown Boston to the east to former industrial land along the South Boston Piers. More than $500 million has been invested in real estate in this area, and more development is expected. Larger projects include the Joseph L. Moakley Federal Courthouse and the 980,000 square-foot Boston Convention and Exhibition Center. Other built and planned projects include office buildings, hotels, retail, and condominiums.

The experience of the Silver Line in Boston shows that both arterial-based BRT systems and grade-separated transitways can attract development.

Laconia Lofts

South End Community Health Center

Area D-4 Police Station



Joseph Moakley Courthouse (Silver Line Phase II)

North Las Vegas MAX, Las Vegas, NV

The North Las Vegas Boulevard corridor is a low density corridor extending from downtown Las Vegas to the north. The system was just inaugurated in the summer of 2004. While general development patterns have still not yet transformed due to the brief period of operation, one casino has already invested in pedestrian facilities and an additional station to attract passengers from the system.

Metro Rapid, Los Angeles, CA

Arterial corridors within the City of Los Angeles have traditionally defined where prominent development occurs. The Metro Rapid program is designed to bring a higher level of service to high transit ridership corridors. In many cases, Metro

Rapid, therefore, reinforces the accessibility and attractiveness of these corridors as sites for transit-supportive development.

One of the first corridors on which Metro Rapid was implemented was the Wilshire Boulevard corridor. This corridor is the most densely developed commercial corridor with the largest concentration of major activity centers and destinations in Southern California. From downtown Los Angeles to Santa Monica, Wilshire Boulevard hosts a mix of high-rise (20 or more stories), mid-rise (8-10 stories), and low-rise (2-5 stories) office and retail buildings. Significant attractions include a complex of museums anchored by the Los Angeles County Museum of Art, downtown Beverly Hills with its offices and tourist-oriented retail, and Westwood Village, a concentration of retail and offices adjacent to the University of California at Los Angeles.

Since the corridor parallels one portion of the Metro Red Line heavy rail subway, the corridor also includes significant new joint development projects set to include high density housing and schools around at least three different stations (Wilshire / Western, Wilshire / Vermont, and MacArthur Park).

LYMMO, Orlando, CA

The LYMMO in Orlando, Florida has playing a vital role in the economic development of Downtown Orlando. Numerous commercial and residential developments have been built since the inauguration of the LYMMO BRT service. By providing a high quality, frequent, and reliable transportation choice for downtown employees, visitors and residents the LYMMO has increased accessibility to public transit and spurred development along its route. The City of Orlando makes use of the LYMMO as a tool to promote development. As a result of this strategy, there are five new office buildings in Downtown Orlando with about one million square feet per building. In addition, six new apartment communities have recently been developed in downtown Orlando.

West Busway, Pittsburgh, PA

The Port Authority of Allegheny County is advertising for joint development opportunities seeking developers interested in using agency-owned land to provide development plans compatible with adjoining park-and-ride lots. Despite the difficult development conditions (narrow railroad corridor with limited commercial activity), some development is being generated. The Borough of Carnegie has recently constructed a municipal building adjacent to a 215 space park-and-ride lot at the terminus of the West Busway. This development includes retail services such as a dry cleaner and a shoe store. The Port Authority is also soliciting development at the West Busway's Carnegie Borough Park-and-Ride and a park-and-ride lot in Moon Township near Pittsburgh International Airport. The Moon Township Development is notable since it is demonstrates how the flexibility of BRT enables the benefits of transit to be transferred to locations not directly adjacent to the major transportation facility. [51]

Martin Luther King Jr. East Busway, Pittsburgh, PA

From its inception, the East Busway was envisioned by state and local officials to stimulate development through the eastern Pittsburgh suburbs. Early efforts included promotion of development and designation of "Enterprise Development Areas" in the municipalities of East Liberty and Wilkinsburg.[52] 54 New Developments within 1500 ft of stations. Since the commencement of service the East Busway has generated $302 million in land development benefits, $225 million due to new construction. Eighty percent of this new corridor development is clustered at station areas.

Negley (Shadyside)

East Liberty (Shadyside)

[51] **Bus Rapid Transit Evaluation of Port Authority of Allegheny County's West Busway Bus Rapid Transit Project**, *U.S. Department of Transportation, Washington, DC, April 2003*

[52] *Pultz, S. and Koffman, D.,* **The Martin Luther King, Jr. East Busway in Pittsburgh, PA,** *U.S. Department of Transportation, Washington, DC, 1987*

4.5 ENVIRONMENTAL QUALITY

4.5.1 Environmental Improvement and BRT

When discussing transportation systems, the primary way to improve the environment is through reduction of vehicular emissions to improve air quality, even though there are also negative impacts in the form of noise and water pollution. There are two broad categories of emissions according to the scope of impact — local or criteria pollutants and global pollutants. Local or criteria pollutants include nitrogen oxides, sulfur oxides, carbon monoxide, volatile organic compounds, lead, and particulate matter of various sizes; and global pollutants include carbon dioxide and other green house gases.

This section focuses mostly on the reduction of emissions of local air pollutants from BRT investments since it usually has the most direct impact on urban environments. Nonetheless, BRT can also have similar positive impacts on other forms of pollution, overall livability, and other environmental objectives.

4.5.2 BRT System Benefits to Environmental Quality

Environmental Improvement Mechanisms

Public transportation improves environmental quality by reducing pollution caused by the transportation system through three distinct, yet cumulative, mechanisms, which are presented in Exhibit 4-6:

Exhibit 4-6: Environmental Improvement Mechanisms

Pollution Reduction Mechanism	Sources of Pollution Reduced	Objective	Significance of Impact
Technology Effect	BRT vehicle emissions	Reduce direct BRT vehicle pollution by using: ▪ Larger (and fewer) Vehicles ▪ Propulsion systems, fuels, and pollution control systems with less emissions	**Moderate** and **Immediate**

Pollution Reduction Mechanism	Sources of Pollution Reduced	Objective	Significance of Impact
Ridership Effect	Emissions from trips using automobiles rather than transit	Attract riders to BRT through improved performance: ▪ Travel Time Savings ▪ Reliability ▪ Brand Identity ▪ Safety and Security	**High** – On a passenger-mile basis, public transportation produces approximately 90% less volatile organic compounds, 95% less carbon monoxide, and nearly 50% less nitrogen oxides and carbon dioxide than identical trips using private automobiles. [53]
System Effect	Vehicle emissions from congestion	Direct – Reduce conflicts between BRT vehicles and other traffic to reduce emissions from all vehicles Indirect – Attract riders to BRT to reduce overall system congestion	**Moderate** – Models have estimated the reduction of overall regional vehicular emissions from reducing both transit emissions and vehicle emissions through reduced congestion to be on the order of several percent.[54] For the transit component of this reduction, segregated running ways for BRT in London have been shown to decrease bus emissions by as much as 60% through more efficient speeds and fewer stops.[55]

BRT System Design Effects on Environmental Quality

In Exhibit 4-7, each BRT design variable is classified according to which mechanism of pollution reduction it affects.

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53 *Shapiro, Hassett and Arnold,* **Conserving Energy and Preserving the Environment: The Role of Public Transportation**, *APTA report, 2002*

54 *Darido, G.,* **Managing Conflicts Between the Environment and Mobility: The Case of Road-Based Transportation and Air Quality in Mexico City**, *MIT, 200*

55 *Bayliss, D.,* **Background Report for the European Conference of Ministers of Transport-OECD Joint Ministerial Session on Transport and the Environment**, *Paris, 1989*

Exhibit 4-7: Potential Environmental Impact of BRT Elements

BRT Element	Design Variables	Technology Effect	Ridership Effect	System Effect
Running Ways	Running Way Segregation		X	X
	Running Way Marking		X	
	Guidance		X	
Stations	All		X	
Vehicles	Vehicle Configuration	X		
	Aesthetic Enhancements		X	
	Passenger Circulation Enhancement		X	
	Propulsion System	X		
Fare Collection	All		X	
ITS	Vehicle Prioritization		X	X
	Driver Assist and Automation		X	
	Operations Mgmt.		X	X
	Passenger Information		X	
	Security Monitoring		X	
Service and Operations Plan	Route Length		X	X
	Route Structure		X	X
	Service Span		X	X
	Service Frequency		X	X
	Station Spacing		X	X

Vehicle Technology and Environmental Quality

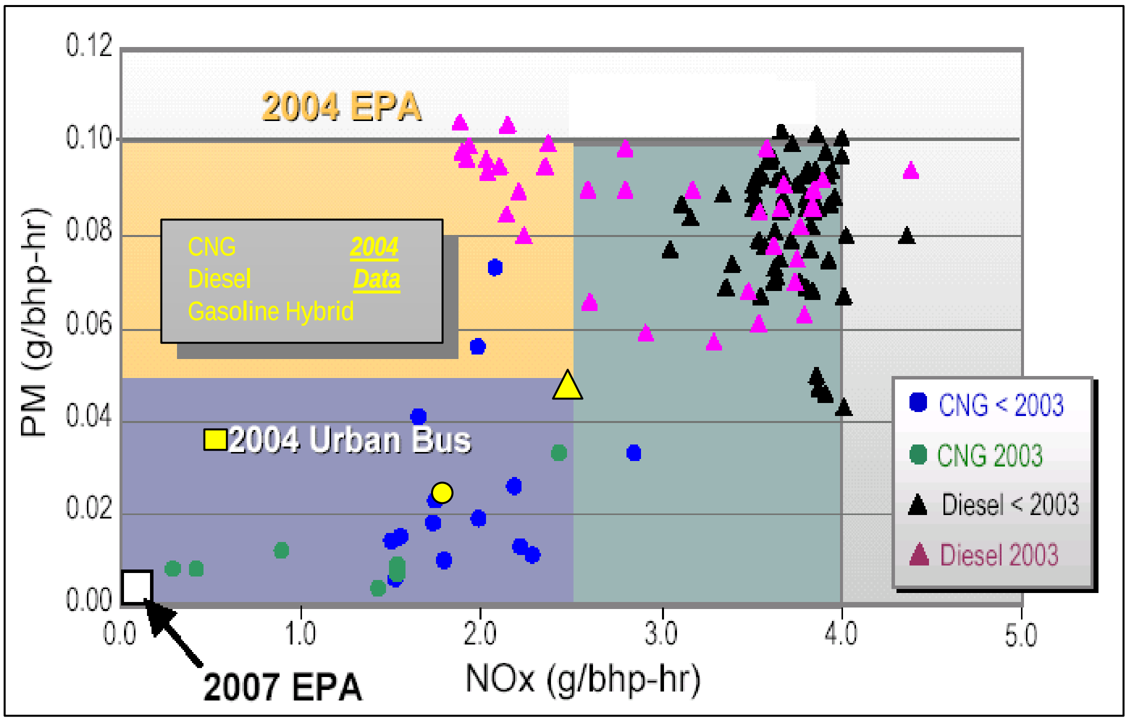
Vehicles provide the most direct impact on environmental quality. The specific characteristics and impacts on environmental quality are discussed in this section.

Alternative vehicle propulsion systems and alternative fuels, as part of a BRT system, have clear benefits for the environment due to lower pollutant emissions or higher energy efficiency. Many transit agencies consider alternative propulsion systems and fuels due to regulations and to support environmental conservation goals. In considering the impact that vehicle technologies have on air quality, it is important to note that the options in vehicle propulsion system, fuel, and emissions control systems are changing rapidly. Even emissions summaries prepared in the year 2000 are relatively obsolete.

The state of the vehicle manufacturing industry, however, is changing as a result of stricter environmental regulations. The focus of vehicle emission control today is on particulate matter (PM) and oxides of nitrogen (NOx) in engine exhaust. The EPA heavy-duty engine regulations in 2007 and 2010 are forcing 80-90% reduction in PM and NOx emissions for bus engines. Adequate and continual maintenance of the propulsion system is also important to respond to the regulated deterioration factors for emission controls throughout the life of the vehicle. As shown in the Exhibit, in 2007, the certification requirements are 0.01 and 0.02 grams per brake-horsepower-hr for PM and NOx, respectively.

Vehicle engine suppliers are in a dramatic state of transition as also shown in the Exhibit 4-8 which plots certified PM and NOx emissions of heavy duty engines. The implications are that pre-2003 engines and current engines have dramatically different emissions performance and that the requirements on both ULSD and CNG engines will be the same in the future for these two criteria.

Exhibit 4-8: Certified Engine Emissions Performance of Diesel, CNG and Hybrid Bus Engines



Source: Lists from EPA/OTAQ and CARB websites of 2003 and 2004 certified engines, certificates and emissions.

Diesel engines fueled by ultra low sulfur diesel (ULSD) and exhaust after-treatment are now achieving PM levels once achieved only by alternative fuel compressed natural gas (CNG) powered buses. Engine controls are being developed to achieve the NOx reduction currently by both ULSD and CNG engines. In California in 2004, as shown in the Exhibit 4-8, one gasoline fueled hybrid-electric bus drive train has been certified. An interim certification procedure for hybrid electric buses is available in California.

Diesel hybrid-electric power trains have already shown performance comparable to current CNG powered buses with acceleration and noise improvements as well. As of 2004, the relative level of emissions reduction is not as much a determining factor in propulsion system choice as it has historically been.

While the emissions control technology is in rapid change, there are even more issues relating to fuel and emissions. Those issues, listed in Exhibit 4-7, may well drive propulsion technology. Exhibit 4-9 provides a qualitative assessment of current propulsion systems and fuel relative to present performance. A plus (+) represents a fuel/engine combination advantage over the other alternatives while a negative sign (-) represents a slight disadvantage for that propulsion system.

In addition to the currently regulated pollutants, interest in other aspects of vehicle propulsion system performance is growing. These include:

- Fuel economy – to promote operating efficiencies and energy security
- Noise – Sound attenuation methods for Hybrids and conventional ICEs are being developed
- Unregulated Air Toxics – using the best available aftertreatment, natural gas has a slight edge over ULSD with both ICE and Hybrid systems
- Ultra-fine Particulate Mater (PM 2.5) – A nationwide monitoring program to assess ultra-fine particles at 2.5 microns is now part of air quality planning requirements. These fine particles are formed by fuel combustion, including by buses, and also in the atmosphere when gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds (all of which are also products of fuel combustion) are transformed in the air by chemical reactions. Fine particles are of concern because they are risk to both human health and the environment.
- Greenhouse Gases

Exhibit 4-9 Propulsion System / Fuel Choices and Emerging Performance Attributes

Performance Measure	Fuel and Propulsion System			
	ULSD ICE Engine	CNG ICE Engine	Diesel Hybrid Electric	Gasoline Hybrid Electric
Fuel Economy			++	+
Energy Security		+	++	+
Audible Noise			+	+
Unregulated Air Toxics	-	+		+
Ultra Fine PM 2.5		+		+
Greenhouse Gases		+	+	+

++ Significant advantage over existing technology

\+ Slight advantage over existing technology

\- Slight disadvantage compared to existing technology

4.5.3 Summary of System Design and Environmental Quality

Experience in United States BRT systems shows that the transit industry is beginning to incorporate alternative propulsion systems and fuels to reduce pollutant emissions. Exhibit 4-10 shows that natural gas (either in compressed or liquid form) are used in Boston, Los Angeles, and Phoenix. Three systems are using ultra-low sulfur diesel (Chicago, Honolulu, and Orlando). Las Vegas MAX vehicles use a hybrid diesel electric vehicles.

Exhibit 4-10: Summary of Vehicle Characteristics Relevant to Pollutant Emissions

	Boston	Chicago	Honolulu	Las Vegas	Los Angeles	Miami	Oakland	Orlando	Phoenix	Pittsburgh
	Silver Line	Neighbor-hood Express	City Express!	North Las Vegas MAX	Metro Rapid	Busway	Rapid Bus	LYMMO	Rapid	Busway
Vehicles										
Vehicle Configuration	Stylized Articulated	Conventional Standard	Conventional Standard	Specialized BRT Vehicle	Conventional Standard	Conventional Standard and Articulated	Stylized Standard	Standard	Specialized Standard	Conventional Standard & Articulated
Propulsion System	ICE - CNG	ICE - Ultra-Low Sulfur Diesel	ICE - Ultra-Low Sulfur Diesel	Diesel Electric	ICE – CNG	ICE – Diesel	ICE – Diesel	ICE – ULSD	ICE – LNG	ICE – Diesel

5.0 CONCLUSIONS AND SUMMARY

The preceding chapters of the Characteristics of BRT (CBRT) report encapsulate the experience with BRT along three dimensions. Chapter 2 presented a summary of the primary physical, operational and cost characteristics of BRT, organized by the six major elements of BRT – Running Ways, Stations, Vehicles, Fare Collection, ITS, and the Service and Operations Plan. Chapter 3 highlighted the attributes of performance affected by the BRT system elements – Travel Time, Reliability, Image and Identity, Passenger Safety and Security, and System Capacity. Chapter 4 discussed the major benefits that BRT systems effect. Each of these chapters included illustrations of specific BRT experience and summaries of BRT systems in the United States and around the world. This presentation of the BRT experience along three dimensions is intended to allow the reader of CBRT to glean insights about BRT from any perspective.

This chapter performs two major functions. First, it provides an overview of BRT experience as presented in the core of the CBRT report. Second, it describes the role of CBRT as a living and dynamic document, intended to reflect the evolving knowledge base related to BRT.

5.1 SUMMARY OF BRT EXPERIENCE

5.1.1 Summary of BRT Elements

Experience in the United States suggests that implementation of more complex BRT system elements is just beginning. Implementation of running ways, stations, and vehicles suggest a wide variety of applications. Some of the more quickly implemented projects demonstrated the least amount of investment in BRT system elements.

Running Ways

BRT systems in the United States have incorporated all types of running ways – mixed flow arterial operation (Los Angeles, Honolulu), mixed flow freeway operation (Phoenix), dedicated arterial lanes (Boston, Orlando), at-grade transitways (Miami), and fully grade-separated surface transitways (Pittsburgh), and subways (Seattle, Boston in late 2004). The only application in the United States of running way guidance occurred in Las Vegas with optical guidance used to provide precision docking at stations. The use of unique running way markings to differentiate BRT running ways was rare, with the use of signing and striping the most common form. This suggests that articulation of brand identity to running ways is still not yet widespread.

Stations

There has been a broad range of sophistication and design attention in BRT stations. Almost universally, BRT station designs are significantly different than those of standard local bus stops, while the level of investment in the stations has generally been related to the level of investment in running way infrastructure. Exclusive transitways are most often paired with the most extensive and elaborate station infrastructure. Most systems incorporated stations designed to allow passing of vehicles at stations through the use of either adjacent mixed flow lanes or passing lanes. Only one system in the United States has platforms high enough to allow level boarding (North Las Vegas MAX).

The mix of station amenities varied across systems. The most common station amenities were seating and trash receptacles. Many systems (e.g., Los Angeles Metro Rapid, Boston's Silver Line, Las Vegas MAX, and AC Transit's Rapid Bus System) have real-time schedule and/or vehicle arrival information. Communications infrastructure such as public telephones and emergency telephones are starting to be installed in systems.

Most systems have intermodal transfer facilities where there are specially designed interfaces with other bus services and rapid rail systems (e.g., Los Angeles, Miami). Stations including park and ride facilities are generally part of systems with exclusive transitways (e.g., Miami-Dade South Busway, Pittsburgh Busways).

Vehicles

Early BRT systems used standard vehicles that were often identical to the rest of a particular agency's fleet. A mix of standard and articulated vehicles reflects the different levels of demand and capacity requirements across BRT systems. Three systems, Los Angeles Metro Rapid, AC Transit's Rapid Bus, and Boston's Silver Line, began operation with standard size 40-foot buses with and are phasing in 60-foot articulated buses as demand grows.

The use of vehicle configurations or aesthetic enhancements to differentiate BRT is gaining momentum. Some agencies have recently added differentiated liveries, logos, and color to these vehicles as a way to differentiate BRT service from other service. As agencies become more conscious of the visual impact of vehicles, they are slowly incorporating Stylized versions of their Conventional Standard and Articulated vehicles. The only case of the use of a Specialized BRT Vehicle is in Las Vegas.

Fare Collection

Use of alternate fare collection processes has been rare in the United States. The only implementation of anything other than a Pay On-Board process is the proof-of-payment system associated with the Las Vegas MAX system. Anecdotal observations suggest that the dwell times at high demand stations of some BRT systems has increased significantly as demand for BRT systems has grown. Over-all running times and reliability, therefore, have been negatively affected. This indicates an opportunity to introduce fare collection processes that allow for multiple-door boarding.

Electronic fare collection using magnetic-stripe cards or smart cards is slowly being incorporated into BRT systems, but implementation is largely driven by agency-wide implementation rather than BRT-specific implementation. Smart cards are gaining wider application than magnetic-stripe cards among BRT systems.

ITS

The most common ITS applications include Transit Signal Priority, Advanced Communication Systems, Automated Scheduling and Dispatch Systems, and Real-Time Traveler Information at Stations and on Vehicles. Installation of Security Systems such as emergency telephones at stations and closed circuit video monitoring is rare, but increasing as newer, more comprehensive systems are implemented.

Service and Operating Plans

In general, the structure of the routes correlated with the degree of running way exclusivity. The service plan for systems using at-grade arterial lanes, either in mixed flow or designated lanes generally incorporated a single BRT route replacing an existing local route or a single BRT route following the same route as a local route, which has its frequency reduced. For example, AC Transit's Rapid Bus, Las Vegas RTC's MAX, Los Angeles Metro's Metro Rapid have a single BRT route overlaid on a local route. Station spacing, generally between 0.5 and 1.0 miles for the BRT route, was higher than that of the local route.

Service plans for systems that use exclusive transitways (Miami-Dade's at-grade South Busway and Pittsburgh's grade-separated transitways) are operated with integrated networks of routes that include routes that serve all stops and a variety of feeders and expresses with integrated off-line and line-haul operation.

Service frequencies correlated with demand in the respective corridors. Individual BRT systems on arterials operated with headways between 5 and 15, with Boston and Los Angeles operating shorter combined headways in some corridors. Services operating on Pittsburgh's exclusive running ways have the lowest combined headways observed in the United States for BRT, approximately 1 minute along the trunk transitway at the maximum load point.

5.1.2 Summary of BRT Performance

Travel Time

With respect to total BRT travel times, BRT projects with more exclusive running ways generally experienced the greatest travel time savings compared to the local bus route. Exclusive transitway projects operated at a travel time rate of 2 to 3.5 minutes per mile (between 17 and 30 miles per hour). Arterial BRT projects in mixed flow traffic or designated lanes operated between 3.5 and 5 minutes per mile (between 12 and 17 miles per hour). Performance in reliability also demonstrated a similar pattern.

Reliability

As expected, systems with more exclusive transitways demonstrated the most reliability and the least schedule variability and bunching. The ability to track reliability changes has been limited by the fact that most transit agencies do not regularly measure this performance attribute. Passenger surveys, however, indicate that reliability is important for attracting and retaining passengers. New automated vehicle location systems, may allow for the objective and conclusive measurement of reliability.

Image and Identity

Performance in achieving a distinct brand identity for BRT has been measured by in-depth passenger surveys. The more successful BRT systems have been able to achieve a distinct identity and position in the respective region's family of transit services. BRT passengers generally had higher customer satisfaction and rated service quality higher for BRT systems than for their parallel local transit services.

Safety and Security

Data measuring the difference in safety and security of BRT systems as compared with the rest of the respective region's transit system have not been collected. Drawing conclusions about the efficacy of BRT elements in promoting safety and security is therefore premature. Data from Pittsburgh suggest that BRT operations on exclusive transitways have significantly fewer accidents per unit (vehicle mile or vehicle hour) of service than conventional local transit operations in mixed traffic. Customer perceptions of "personal safety" or security reveal that customers perceive BRT systems to be safer than the rest of the transit system.

Capacity

For virtually all BRT systems implemented in the United States, capacity has not been an issue. To date, none of them have been operated at their maximum capacity. On all systems, there is significant room to expand operated capacity by operating larger vehicles, higher frequencies, or both.

5.1.3 Summary of BRT System Benefit Experience

Ridership

There have been significant increases in transit ridership in virtually all corridors where BRT has been implemented. Though much of the ridership increases have come from passengers formerly using parallel service in other corridors, passenger surveys have revealed that much of the increased number of trips have been made by individuals that used to drive or be driven, passengers that use to make the same trip by walking (e.g., the Boston's Silver Line Phase I) and by passengers taking advantage of BRT's improved level of service to make trips that were not made by any mode previously.

Increases in BRT ridership have come from both individuals that used to use transit and totally new transit users that have access to automobiles.

Aggregate analyses of ridership survey results suggest two conclusions:

- The ridership impact of BRT implementation has been comparable to that experienced with LRT investment of similar scope and complexity
- The ridership increases due to BRT implementation exceed those that would be expected as the result of simple level of service improvements. The implication here is that the identity and passenger information advantages of BRT are seen positively by potential BRT customers when they make their travel decisions.

Capital Cost Effectiveness

BRT demonstrates relatively low capital costs per mile of investment. It is worth noting, however, that recently implemented BRT systems have focused on less capital-intensive investments. More capital intensive investments will begin service in the next few years. Depending on the operating environment, BRT systems are able to achieve service quality improvements (such as travel time savings of 15 to 25 percent and increases in reliability) and ridership gains that compare favorably to the capital costs and the short amount of time to implement BRT systems. Furthermore, BRT systems are able to operate with lower ratios of vehicles compared to total passengers.

Operating Cost Efficiency

BRT systems are able to introduce higher operating efficiency and service productivity into for transit systems that incorporate them. Experience shows that when BRT is introduced into corridors and passengers are allowed to choose BRT service, corridor performance indicators (such as passengers per revenue hour, subsidy per passenger mile, and subsidy per passenger) improve. Furthermore, travel time savings and higher reliability enables transit agencies to operate more vehicle miles of service from each vehicle hour operated.

Transit-Supportive Land Development

In places where there has been significant investment in transit infrastructure and related streetscape improvements (e.g., Boston, Pittsburgh, Ottawa, Vancouver), there have been significant positive development effects. In some cases, the development has been adjacent to transit to the transit facility, while in other places the development has been integrated with the transit stations. Experience is not yet widespread enough to draw conclusions on the factors that would result in even greater development benefits from BRT investment, although the research on linking transit and land development, in general, can provide a useful foundation of knowledge.

Environmental Quality

Documentation of the environmental impacts of BRT systems is rare. Experience does show that there is improvement to environmental quality due to a number of factors. Ridership gains suggest that some former automobile users are using transit as a result of BRT implementation. Transit agencies are serving passengers with fewer hours of operation, potential reducing emissions. Most importantly, transit agencies are adopting vehicles with alternative fuels, propulsion systems, and pollutant emissions controls. Progress in reducing emissions of particulate matter and oxides of nitrogen is on pace to meet standards imposed by the United States Environmental Protection Agency.

5.2 SUSTAINING THE CHARACTERISTICS OF BUS RAPID TRANSIT FOR DECISION-MAKING REPORT

The ***Characteristics of Bus Rapid Transit for Decision-Making*** report presents a useful compendium of information for supporting BRT planning, design and operations. This edition of CBRT presents a single snapshot of the collective experience of BRT, which, in the United States, is just beginning. In order to sustain the utility of CBRT as a key BRT information source, CBRT must incorporate information from future BRT applications and several different research and development activities.

5.2.1 Supplemental Evaluation of Operating BRT Projects

The CBRT builds upon a tradition of research on the implementation of BRT elements and BRT projects. FTA has completed evaluation efforts for BRT projects in Pittsburgh (Martin Luther King Jr. Busway and West Busway), Miami, and Orlando. It has also initiated evaluation of BRT projects in Boston, Oakland, and Las Vegas. In addition, project implementation agencies have completed their own individual evaluation efforts. Future editions for CBRT can incorporate information from supplemental evaluations of operational systems.

Often, original evaluations did not address specific issues or did not measure a specific aspect of BRT. Following up an evaluation to explore a new topic (e.g., safety and security) or to update previous measurements (e.g., using new measurement tools to characterize reliability) can provide a more complete picture of select BRT systems.

5.2.2 Evaluation of New BRT Projects

BRT projects currently in development can provide additional sources of information. At least four additional BRT projects will begin operation in 2005 and 2006. These include:

- Orange Line (Los Angeles)
- Euclid Corridor (Cleveland)
- Phase I BRT Corridor (Eugene, OR)
- Hartford - New Britain Busway (Hartford, CT)

These projects represent useful cases demonstrating dedicated arterial lanes and exclusive transitways. Establishing baseline conditions is critical for maximizing the usefulness of an evaluation.

5.2.3 Compiling Ongoing Information on Performance and Benefits

In order to draw more definitive conclusions about the implementation of BRT, it is often important to have a large set of data on several systems over a period of several years.

While other modes benefit from mechanisms for collecting and reporting data such as the National Transit Database (NTD), a common platform or methodology for collecting and reporting BRT system data has yet to be developed. The CBRT represents an attempt to report on BRT experience (major project elements, performance, and benefits) in a single unified format. Future updates can benefit from a single protocol for collecting data on BRT. This protocol would emphasize two key qualities:

- Consistency – data collected consistently with common definitions and common units of measurement allow for effective comparison across projects
- Regularity – data collected at regular intervals allows for a characterization of how BRT systems and their performance evolve over time
- Simplicity – collecting data regularly requires that the methods to collect it be simple and easy to understand

5.2.4 Incorporating General Transit Research

This report has drawn heavily upon general research and syntheses of experience in transit, including several documents produced by industry groups such as the American Public Transportation Association (APTA) and programs such as the Transit Cooperative Research Program (TCRP). The work being conducted under the auspices of TCRP Project A-23A will advance research on BRT even further. This openness to knowledge from the broader transit community acknowledges the notion that BRT systems include elements that are not exclusive to BRT. The development of BRT systems involves conscious integration of several transit elements that can be implemented independently. Because the experience in these elements is broad, the body of research from which CBRT draws should be just as broad. The CBRT can thus serve as a focal point for this dialogue between the transit research community and BRT system planners.

5.3 CLOSING REMARKS

This edition of the CBRT represents a snapshot of BRT experience as of the summer of 2004. It contains a wealth of data and information, but there is much about BRT that can be explored further. This is why the CBRT is intended to be a dynamic document, one that evolves along with the experience of the transit community with BRT. As the number and sophistication of BRT applications increases, CBRT will reflect this experience in future editions. Data on system experience in future editions will allow for the analyses to be more robust and for lessons learned to be more definitive. The FTA encourages the use of CBRT as a key tool to disseminate information on the evolution of BRT to the transit community.

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GLOSSARY OF TERMS RELATED TO BRT

TERM	DEFINITION
Alighting	When a passenger exits a vehicle.
Articulated Bus	A bus composed of two vehicle sections connected by an articulated joint. An articulated bus has a higher passenger capacity than a standard bus.
Automated Passenger Counter (APC)	Technology that counts passengers automatically when they board and alight vehicles. APC technologies include treadle mats (registers passengers when they step on a mat) and infrared beams (registers passengers when they pass through the beam). APC is used to reduce the costs of data collection and to improve data accuracy.
Automated Vehicle Location (AVL)	Technology used to monitor bus locations on the street network in real-time. AVL is used to improve bus dispatch and operation, and allow for quicker response time to service disruptions and emergencies.
Barrier Enforced Fare Payment System	A fare collection system (process) where passengers pay fares in order to pass through turnstiles or gates prior to boarding the vehicle. This is done to reduce vehicle dwell times.
Barrier-Free Proof-of-Payment (POP) System	A fare collection system (process) where passengers purchase fare media before boarding the vehicle, and are required to carry proof of valid fare payment while on-board the vehicle. Roving vehicle inspectors verify that passengers have paid their fare. This is done to reduce vehicle dwell times.
Boarding	When a passenger enters a vehicle.
Branding	The use of strategies to differentiate a particular product from other products, in order to strengthen its identity. In the context of BRT systems, branding often involves the introduction of elements to improve performance and differentiate BRT systems such as the use of vehicles with a different appearance from standard bus services, distinct station architecture and the use of distinct visual markers such as color schemes and logos.
Brand Identity	Represents how a particular product is viewed among the set of other product options available. In the context of BRT systems, brand identity is necessary so that passengers distinguish BRT services from other transit services.

TERM	DEFINITION
Bus Bulb	Where a section of sidewalk extends from the curb of a parking lane to the edge of an intersection or off-set through lane. This creates additional space for passenger amenities at stations, reduces street crossing distances for pedestrians, and eliminates lateral movements of buses to enter and leave stations. However, this may also produce traffic queues behind stopped buses.
Bus Rapid Transit (BRT)	A flexible, rubber-tired form of rapid transit that combines stations, vehicles, running way, and ITS elements into an integrated system with a strong identity. BRT applications are designed to be appropriate to the market they serve and their physical surroundings. BRT can be implemented in a variety of environments, ranging from rights of way totally dedicated to transit (surface, elevated, or underground) to mixed traffic rights of way on streets and highways.
Bus Street	Street that is dedicated to bus use only.
Capacity	The maximum number of passengers that could be served by a BRT system.
Capacity, Person	The maximum number of passengers that can be carried along the critical section of the BRT route during a given period of time, under specified operating conditions, without unreasonable delay, hazard, or restriction and with reasonable certainty.
Capacity, of Facilities	The number of vehicles per period of time that use a specific facility (i.e., running way or station).
Capacity, of Vehicle	The maximum number of seated and standing passengers that a vehicle can safely and comfortably accommodate. This is determined by the vehicle configuration.
Contextual Design	How well a BRT system demonstrates a premium, quality design and is integrated with the surrounding communities.
Demand	The actual number of passengers attracted to use a BRT system.

TERM	DEFINITION
Designated Lane	A lane reserved for the exclusive use of BRT or transit vehicles. Dedicated lanes can be located in different positions relative to the arterial street and are classified accordingly: Concurrent Flow Curb – Next to the curb, used by buses to travel in the same direction as the adjacent lane. Concurrent Flow Interior – Between curb parking and the adjacent travel lane, used by transit vehicles to travel in the same direction as the adjacent travel lane. This is done in situations where curb parking is to be retained. Contraflow Curb – Located next to the curb, used by transit vehicles to travel in the opposite direction of the normal traffic flow. Could be used on one-way streets, or for a single block on two-way streets to enable buses to reverse direction. Median – Within the center of a two-way street.
Dual-Mode Propulsion	A propulsion systems that offers the capability to operate with two different modes, usually as a thermal (internal combustion) engine and in electric (e.g., trolley) mode
Dwell Time	The time associated with a vehicle being stopped at a curb or station for the boarding and alighting of passengers. BRT systems often intend to reduce dwell times to the extent possible, through such strategies as platform height, platform layout, vehicle configuration, passenger circulation enhancements, and the fare collection process.
Dwell Time Reliability	Ability to maintain consistent dwell times at stations. BRT systems often intend to improve dwell time reliabilities to the extent possible, through such strategies as platform height, platform layout, vehicle configuration, passenger circulation enhancements, and the fare collection process.
Driver Assist and Automation Technology	Form of technology that provides automated controls for BRT vehicles. Examples include collision warning, precision docking, and vehicle guidance systems.
Fare Structure	Establishes the ways that fares are assessed and paid. The two basic types of fare structures are flat fares (same fare regardless of distance or quality of service) and differentiated fares (fare depends on length of trip, time of day, and/or type of service).

TERM	DEFINITION
Fare Transaction Media	Type of media used for fare payment. Examples include cash (coins and bills), tokens, paper media (tickets, transfers, flash passes), magnetic stripe media, and smart cards. Electronic fare transaction media (i.e., magnetic stripe media or smart cards) can reduce dwell times and fare collection costs, increase customer convenience, and improve data collection.
Global Positioning System (GPS)	The use of satellites and transponders to locate objects on the earth's surface. GPS is a widely used technology for AVL systems.
High Occupancy Vehicle (HOV) Lane	A street or highway lane designated for use by vehicles with more than one passenger only, including buses. HOV lanes are often used on freeways.
Hybrid-Electric Drive	A propulsion system using both an internal combustion engine and electric drives that incorporates an on-board energy storage device.
Intelligent Transportation Systems (ITS)	Advanced transportation technologies that are usually applied to improve transportation system capacity or to provide travelers with improved travel information. Examples of ITS applications with relevance to BRT systems include vehicle prioritization, driver assist and automation technology, operations management technology, passenger information, safety and security technology, and support technologies.
Internal Combustion Engine (Thermal Engine)	An engine that operates by burning its fuel inside the engine. Combustion engines use the pressure created by the expansion of the gases to provide energy for the vehicle. ICEs typically use fuels such as diesel or natural gas (in either compressed gas or liquefied form).
Level Boarding	An interface between station platform and vehicle that minimizes the horizontal and vertical gap between the platform edge and the vehicle door area, which speeds up passenger boarding/alighting times and does not require the use of wheelchair lifts or ramps. Level boarding is often done through the use of station platforms and low-floor vehicles.
Low-Floor Vehicle	A vehicle designed with a lower floor (approximately 14 inches from pavement), without stairs or a wheelchair lift. Use of low-floor vehicles could be done in combination with station platforms to enable level boarding, or could be done stand-alone such that passengers are required to take one step up or use a wheelchair ramp to board the vehicle.
Multiple-Door Boarding	Passengers are allowed to board the vehicle at more than one door, which speeds up boarding times. This typically requires off-board fare collection.

TERM	DEFINITION
Operations Management Technology	Automation methods that enhance the management of BRT fleets to improve operating efficiencies, support service reliability, and/or reduce travel times. Examples include automated scheduling dispatch, vehicle mechanical monitoring and maintenance, and vehicle tracking systems.
Passing Capability	The ability for vehicles in service to pass one another. Bus pull-outs and passing lanes at stations are two primary ways to enhance passing capability for a BRT system.
Passenger Circulation Enhancement	Features that govern passenger accessibility to vehicles and circulation within vehicles. Examples include alternative seat layouts, additional door channels, and enhanced wheelchair securements.
Passenger Information System	Technologies that provide information to travelers to improve customer satisfaction. The most common application relevant to BRT systems is the real-time provision of information pertaining to schedules, wait times, and delays to passengers at stations or on-board vehicles using variable message signs and an automated vehicle location technology.
Pay On-Board System	A fare collection system (process) Passengers pay fares on-board the vehicle at the farebox, or display valid fare media to the bus operator.
Platform	A station area used for passenger boarding and alighting. A side platform is adjacent to the curb or a running way. A center platform is located between the vehicle running way and the center of the running way, or median; this is less common because it requires non-standard vehicle door locations.
Platform Height	Height of the platform relative to the running way. The three basic options for platform height are the standard curb, the raised curb, and the level platform.
Platform Layout	Design of the platform with respect to vehicle accommodation. The three basic options for platform layout are the single vehicle length platform, the extended (i.e., multiple vehicle) platform with un-assigned berths, and the extended platform with assigned berths.
Precision Docking System	A guidance system used to accurately steer vehicles into alignment with station platforms or curbs. These may be magnetic or optical-based, and require the installation of markings on the pavement (paint or magnets), vehicle-based sensors to read the markings, and linkages with the vehicle steering system.

TERM	DEFINITION
Propulsion System, Vehicle Propulsion System	The means of delivering power to enable vehicle movement. The most common propulsion systems for BRT vehicles include internal combustion engines fueled by diesel or compressed natural gas, electric drives powered by the use of an overhead catenary, and hybrid-electric drives with an on-board energy storage device. The choice of propulsion system affects vehicle capital costs, vehicle operating and maintenance costs, vehicle performance, ride quality, and environmental impacts.
Queue Jumper	A designated lane segment or traffic signal treatment at signalized locations or other locations where traffic backs up. Transit vehicles use this lane segment to bypass traffic queues (i.e., traffic backups). A queue jumper may or may not be shared with turning traffic.
Route Length	The length of the route affects what locations the route serves and the resources required to operate that route.
Route Structure	How stations and running ways are used to accommodate different vehicles that could potentially be serving different routes.
Running Time	Time that vehicles spend moving from station to station along the running way. BRT systems are designed to reduce running times to the extent possible, through such strategies as running way segregation, passing capability, station spacing, ITS, and schedule control.
Running Time Reliability	Ability to maintain consistent running times along a route. BRT systems are designed to improve running time reliabilities to the extent possible, through such strategies as running way segregation, passing capability, station spacing, ITS, and schedule control.
Running Way	The space within which the vehicle operates. For BRT systems, the running way could be a fully grade-separated exclusive transitway, an at-grade transitway, a designated arterial lane, or a mixed flow lane. BRT vehicles need not operate in a single type of running way for the entire route length.
Running Way Marking	The visible differentiation of the running ways used by BRT vehicles from other running ways. Signage and striping, raised lane delineators, and alternate pavement color/texture represent three major techniques.
Running Way Segregation	Level of segregation, or separation, of BRT vehicles from general traffic. A fully grade-separated exclusive transitway for BRT vehicles represents the highest level of segregation, followed by an at-grade transitway (second highest); a designated arterial lane (third highest); and a mixed flow lane (lowest).

TERM	DEFINITION
Safety and Security Technology	Systems that enhance the safety and security of transit operations. Examples include silent alarms on the vehicle that can be activated by the driver, and voice and/or video surveillance monitoring systems in stations or on-board vehicles.
Schedule Control	How vehicle on-time performance is monitored, either to meet specified schedules or to regulate headways. Headway-based control is more common for very high frequency routes.
Service Frequency	The interval of time between in-service vehicles on a particular route. Determines how long passengers must wait at stations, and the number of vehicles required to serve a particular route. Service frequencies for BRT systems are typically high relative to standard bus services.
Service Reliability	Qualitative characteristics related to the ability of a transit operation to provide service that is consistent with its plans and policies and the expectations of its customers.
Service Span	The period of time that a service is available to passengers. Examples include all day service and peak hour only service.
Signal Timing/Phasing	Involves changes to the normal traffic signal phasing and sequencing cycles in order to provide a clear path for oncoming buses.
Station	Location where passengers board and alight the vehicle. The BRT stations can range from simple stops or enhanced stops to , designated station and the intermodal terminal or transit center. A station often has more passenger amenities than a stop (i.e., benches, shelters, landscaping, traveler information).
Station Access	Means of linking stations with adjacent communities in order to draw passengers from their market area. Examples include pedestrian linkages (i.e., sidewalks, overpasses, pedestrian paths) and park-and-ride facilities.
Station and Lane Access Control	Allows vehicle access to dedicated BRT running ways and stations with variable message signs and/or gate control systems.
Station Spacing	The spacing between stations impacts passenger travel times and the number of locations served along the route. Station spacings for BRT systems are typically farther apart relative to standard bus services.
Support Technologies	Technologies used to support ITS applications. Examples include advanced communication systems, archived data, and automated passenger counters.

TERM	DEFINITION
Ticket Vending Machine (TVM)	A fixed machine that accepts a combination of cash, stored-value media, and credit cards to dispense valid tickets and other fare media
Transfer Time	The time associated with a passenger waiting to transfer between particular transit vehicles. The network design determines where passengers need to make transfers. Service frequency and reliability are the primary determinants of transfer time.
Transit Signal Priority	Adjustments in signal timing to minimize delays to buses. Passive priority techniques involve changes to existing signal operations. Active priority techniques involve adjustments of signal timing after a bus is detected (i.e., changing a red light to a green light or extending the green time).
Transitway / Busway	Traffic lane dedicated to exclusive use of transit vehicles that is physically separated from other traffic lanes. May or may not be grade separated.
Validator	A device that reads a fare instrument (fare transaction medium) to verify if a fare paid is valid for the trip being taken by the passenger
Variable Message Sign (VMS)	A sign that provides flashing messages to its readers. The message posted on the sign is variable and can be changed in real-time.
Vehicle Configuration	The combination of length (standard, articulated, or specialized), body type (conventional, stylized, or specialized), and floor height (standard or low-floor) of the vehicle. In practice, BRT systems can use any combination of different vehicle configurations on a single running way.
Vehicle Guidance System	A guidance system used to steer vehicles on running ways while maintaining speed. These may be magnetic, optical, or GPS-based, and require the installation of markings on the pavement (paint or magnets), vehicle-based sensors to read the markings, and linkages with the vehicle steering system. Guidance can be lateral (side-to-side to keep buses within a specified right-of-way) or longitudinal (to minimize the following distance between vehicles).
Vehicle Prioritization	Methods to provide travel preference or priority to BRT services. Examples include signal timing/phasing, station and lane access control, and transit signal priority.
Wait Time	The time associated with a passenger waiting at a station before boarding a particular transit service. Service frequency and reliability are the primary determinants of wait time.

SUMMARY OF BRT SYSTEM CHARACTERISTICS

	Boston Silver Line	Chicago Western Avenue Express (X49)	Chicago Irving Park Express (X80)	Chicago Garfield Express (X55)	Honolulu City Express A
Running Way					
Mixed Flow Lanes (mi.)	0.2	18.3	9.0	9.4	19.6
Designated Lanes (mi.)	2.2				
At-Grade Exclusive Lanes (mi.)					
Grade-Separated Exclusive Lanes (mi.)					
Guidance	-	-	-	-	-
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Specialized BRT Vehicle	Conventional Standard (40')	Conventional Standard (40')	Conventional Standard (40')	Conventional Articulated (60')
Aesthetic Enhancements	Specialized Livery				Specialized Livery
Passenger Circulation Enhancements	Additional Door Channels				
Propulsion System		Diesel ICE	Diesel ICE	Diesel ICE	ICE – Ultra-Low Sulfur Diesel
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On Board	Pay On Board	Pay On Board	Pay On-Board
Fare Media	Cash & Paper	Cash & Paper; Magnetic Stripe	Cash & Paper; Magnetic Stripe	Cash & Paper; Magnetic Stripe	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat	Flat
ITS					
Vehicle Prioritization	Transit Signal Priority (in 2004)				
Driver Assist and Automation					
Operations Mgmt.	Advanced Communication, Auto Dispatch, AVL	AVL	AVL	AVL	
Passenger Information	Station, Telephone	Station	Station	Station	Station, Telephone, Internet
Service Plan					
Route Length	2.37	18.3	8.98	9.44	19.6
Route Structure	All-Stop Replacement of Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Headway in Minutes)	4	9	12	11	11

	Honolulu City Express B	Honolulu City Express C	Las Vegas North Las Vegas MAX	Los Angeles Metro Rapid Wilshire	Los Angeles Metro Rapid Ventura
Running Way					
Mixed Flow Lanes (mi.)	7.0	30.0	2.9	25.7	16.7
Designated Lanes (mi.)			4.7		
At-Grade Exclusive Lanes (mi.)					
Grade-Separated Exclusive Lanes (mi.)					
Guidance	-	-	Precision Docking at Stations	-	-
Passing Capability	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane	Adjacent Mixed Flow Lane
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Designated Station	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Level Platform	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Conventional Articulated (60')	Conventional Articulated (60')	Specialized BRT Vehicle	Conventional Standard (40')	Standard
Aesthetic Enhancements	Specialized Livery	Specialized Livery	Specialized Livery, Large Windows,	Specialized Livery, Large Windows	Specialized Livery, Large Windows
Passenger Circulation Enhancements			Alternate Seat Layout, Internal Bicycle Racks		
Propulsion System	ICE – Ultra-Low Sulfur Diesel	ICE – Ultra-Low Sulfur Diesel	Diesel Electric Hybrid	ICE – CNG	ICE – CNG
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On-Board	Proof-of-Payment	Pay On-Board	Pay On-Board
Fare Media	Cash & Paper	Cash & Paper	Cash, Magnetic Stripe	Cash & Paper	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat	Flat
ITS					
Vehicle Prioritization			Transit Signal Priority	Transit Signal Priority	
Driver Assist and Automation			Precision Docking	-	Loop Detectors
Operations Mgmt.			Advanced Communication, AVL	Advanced Communication, Auto Dispatch, AVL	Advanced Communication, AVL
Passenger Information	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone Internet	Station, Telephone, Internet	Station, Telephone, Internet
Service Plan					
Route Length	7.0	30.0	7.6	25.7	16.7
Route Structure	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Headway in Minutes)	30	30	12	9	

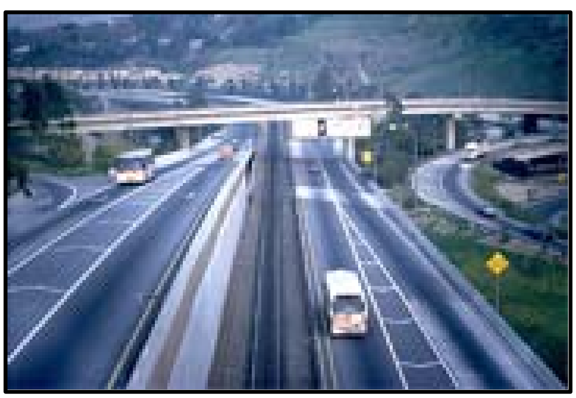
	Los Angeles Metro Rapid Vermont	Los Angeles Metro Rapid Crenshaw	Los Angeles Metro Rapid Van Nuys	Los Angeles Metro Rapid Broadway	Los Angeles Metro Rapid Florence
Running Way					
Mixed Flow Lanes (mi.)	11.9	18.8	21.4	10.5	10.3
Designated Lanes (mi.)	-		-	-	-
At-Grade Exclusive Lanes (mi.)	-		-	-	-
Grade-Separated Exclusive Lanes (mi.)	-		-	-	-
Guidance	-	-	-	-	-
Passing Capability	-		-	-	-
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	1	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Standard	Standard	Standard	Standard	Standard
Aesthetic Enhancements	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery, Large Windows	Specialized Livery, Large Windows
Passenger Circulation Enhancements					
Propulsion System	ICE – CNG	ICE – CNG	ICE – CNG	ICE – CNG	ICE – CNG
Fare Collection					
Fare Collection Process	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	Cash & Paper	Cash & Paper	Cash & Paper	Cash & Paper	Cash & Paper
Fare Structure	Flat	Flat	Flat	Flat	Flat
ITS					
Vehicle Prioritization					
Driver Assist and Automation	Loop Detectors	Loop Detectors	Loop Detectors	Loop Detectors / Infrared Sensors	Loop Detectors
Operations Mgmt.	Advanced Communication, AVL	Loop Detectors / Infrared Sensors	Advanced Communication, AVL	Advanced Communication, AVL	Advanced Communication, AVL
Passenger Information	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet	Station, Telephone, Internet
Service Plan					
Route Length	11.9	18.8	21.4	10.5	10.3
Route Structure	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local	All-Stop Overlay onto Local
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Headway in Minutes)	4	13	15	30	11

	Orlando LYMMO	Miami Busway MAX	Oakland Rapid	Pittsburgh East Busway	Pittsburgh South Busway
Running Way					
Mixed Flow Lanes (mi.)			14.0	10.5	10.3
Designated Lanes (mi.)	-		-	-	-
At-Grade Exclusive Lanes (mi.)	3.0	8	-	-	-
Grade-Separated Exclusive Lanes (mi.)	-		-	-	-
Guidance	-	-	-	-	-
Passing Capability	-	Bus Pullouts	-	-	-
Stations					
Station Type	Enhanced Shelter	Designated Station	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	2	3	1	1	1
Station Access	Pedestrian Focus	2 P&R Lots	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Standard, Articulated, Minis	Standard, Articulated, Minis	Stylized Standard (40.5')	Standard	Standard
Aesthetic Enhancements	Specialized Livery		Specialized Red, White and Green Livery	Specialized Livery, Large Windows	Specialized Livery, Large Windows
Passenger Circulation Enhancements	Alternate Seat Layout		Additional Door Channels; Enhanced Wheelchair Securement		
Propulsion System	ICE - Diesel	ICE – Diesel	ICE – CNG	ICE – CNG	ICE – CNG
Fare Collection					
Fare Collection Process	N/A (Free Fares)	Pay on Board	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	N/A	Cash, paper swipe card	Cash & Paper, Smart Cards	Cash & Paper	Cash & Paper
Fare Structure	Free	Flat	Flat	Flat	Flat
ITS					
Vehicle Prioritization		Transit Signal Priority	Transit Signal Priority		
Driver Assist and Automation		X		Loop Detectors / Infrared Sensors	Loop Detectors
Operations Mgmt.	AVL/Wi-Fi	X	Advanced Communication, Auto Dispatch, AVL	Advanced Communication, AVL	Advanced Communication, AVL
Passenger Information	Station, Internet	Station, PDA, Vehicle	Station, PDA, Vehicle	Station, Telephone, Internet	Station, Telephone, Internet
Service Plan					
Route Length	3	8	14.0	10.5	10.3
Route Structure	All-Stop Replacement of Local	All-Stop, Limited, Express	All-Stop Overlay onto Local	All-Stop Parallel to Local, Express	All-Stop Parallel to Local, Express
Service Span	All Day	All Day	All Day	All Day	All Day
Service Frequency (Peak Headway in Minutes)	5	10	12	30	11

	Pittsburgh	Phoenix	Phoenix	Phoenix	Phoenix
	West Busway	Rapid I-10 East	RAPID I-10 West	RAPID SR-51	RAPID I-17
Running Way					
Mixed Flow Lanes (mi.)		6.5	4.8	12.3	8.0
Designated Lanes (mi.)	-	14.0	8.0	10.3	11.5
At-Grade Exclusive Lanes (mi.)	3.0	-	-	-	-
Grade-Separated Exclusive Lanes (mi.)	-	-	-	-	-
Guidance	-	-			
Passing Capability	-	Bus pullouts	Bus pullouts	Bus pullouts	Bus pullouts
Stations					
Station Type	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter	Enhanced Shelter
Platform Height	Standard Curb	Standard Curb	Standard Curb	Standard Curb	Standard Curb
Platform Length (No. of Vehicles)	2	1	1	1	1
Station Access	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus	Pedestrian Focus
Vehicles					
Vehicle Type	Standard, Articulated, Minis	Stylized Standard	Stylized Standard	Stylized Standard	Stylized Standard
Aesthetic Enhancements	Specialized Livery	Specialized Livery	Specialized Livery	Specialized Livery	Specialized Livery
Passenger Circulation Enhancements					
Propulsion System	Diesel	LNG	LNG	LNG	LNG
Fare Collection					
Fare Collection Process	N/A (Free Fares)	Pay On-Board	Pay On-Board	Pay On-Board	Pay On-Board
Fare Media	N/A	Cash, Mag	Cash, Mag	Cash, Mag	Cash, Mag
Fare Structure	Free	Diff	Diff	Diff	Diff
ITS					
Vehicle Prioritization		Transit Signal Priority at 1 intersection	Transit Signal Priority at 1 intersection	Transit Signal Priority at 1 intersection	Transit Signal Priority at 1 intersection
Driver Assist and Automation		Collision Warning	Collision Warning	Collision Warning	Collision Warning
Operations Mgmt.	AVL/Wi-Fi	Advanced Communication, AVL/Orbital	Advanced Communication, AVL/Orbital	Advanced Communication, AVL/Orbital	Advanced Communication, AVL/Orbital
Passenger Information	Station, Internet	Station, Internet Vehicle, PDA	Station, Internet Vehicle, PDA	Station, Internet Vehicle, PDA	Station, Internet Vehicle, PDA
Service Plan					
Route Length	3	20.5	13	19.25	19.5
Route Structure	All-Stop Parallel to Local, Express	Express	Express	Express	Express
Service Span	All Day	Weekday Peak Hour Only	Weekday Peak Hour Only	Weekday Peak Hour Only	Weekday Peak Hour Only
Service Frequency (Peak Headway in Minutes)	5	10	10	10	10

BRT PHOTO GALLERY

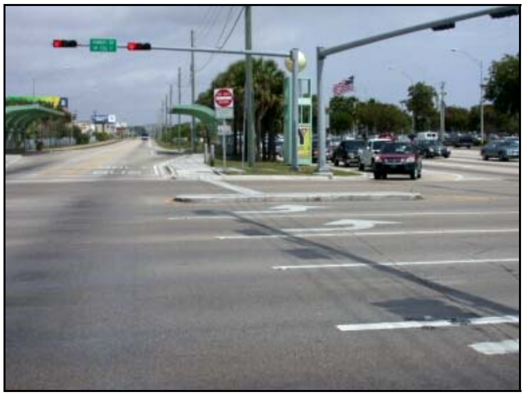
The images in this gallery of photographs present examples of applications of BRT elements throughout the United States and around the world.

Description	Photograph
Running Way – Mixed flow Lane operation Metro Rapid Los Angeles	
Running Way – Fully Grade-Separated Exclusive Transitways East Busway Pittsburgh	
Running Way – Fully Grade-Separated Exclusive Transitways El Monte Busway, Los Angeles	

Description	Photograph
Running Way – Fully Grade-Separated Exclusive Transitways East Busway, Pittsburgh	
Running Way - Passing Capability Options, Passing Lanes at Stations Ottawa, Canada	
Running Way – At-Grade Transitways Pittsburgh	
Running Way – Bus Lanes	

Description	Photograph
Running Way – Running Way Marking Coimbra blue line on cobblestone street to indicate path of transit line	
Running Way – Differentiated Pavement, LYMMO, Orlando, FL	
Running Way – Running Way marking – Alternative Pavement and Pavement Markings LYMMO, Orlando, FL	
Running Way – Raised Running Way Delineators	

Description	Photograph
Running Way- Running Way Marking Colored Pavement for Bus Lane, Wellington, New Zealand	
Running Way – Running Way Marking – Alternate Pavement Color Nagoya, Japan	
Running Way – Running Way Marking – Raised Lane Delineators, Guanajuato, Mexico	
Running Way – Traffic Signage for Contraflow Lanes Montreal, Canada	

Description	Photograph
Running Way – Traffic Signage – Orlando, FL	
Running Way – Traffic Signage – Deter Autos, LYMMO, Orlando, FL	
Running Way – Traffic Signage to Deter Autos, South Busway Miami-Dade, FL	
Running Way – Traffic Signage to Deter Autos, South Busway, Miami-Dade, FL	

Description	Photograph
Running Way – Traffic Signage to Deter Autos, Vancouver, Canada	
Running Way – Traffic Signage, Silver Line, Boston, MA	
Running Way – Traffic Signals, Miami-Dade, FL	
Running Way and ITS – Traffic Signage and Transit Signal Priority signal Orlando, FL	

Description	Photograph
Running Way and Stations – Rouen, France	
Running Way and Stations, and Vehicle – Civis Vehicle docking at station in Rouen, France	
Running Way – Guidance Optical Guidance Markers in Rouen France	
Running Way – Guidance Optical Guidance Markers in Rouen France, View through Windshield of a Vehicle following a car	

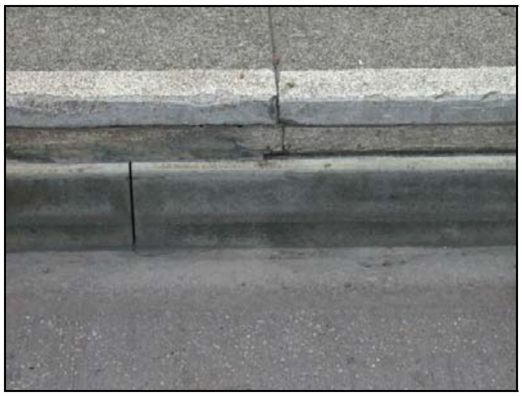
Description	Photograph
Running Way – Guidance View through Windshield following Optical Guidance Markers	
Running Way – Guidance Vehicle following Optical Guidance Markers on a test track in Las Vegas	
Running Way – Guidance Electromagnetic Guidance	
Running Way – Guidance Mechanical Guidance	

Description	Photograph
Running Way and Vehicle – Silver Line, Boston, MA	
Running Way, Station, and Vehicle – LYMMO, Orlando, FL	
Station – Architecture of station at South East Busway in Brisbane, Australia	
Station – Designated MAX Station, Las Vegas, NV	

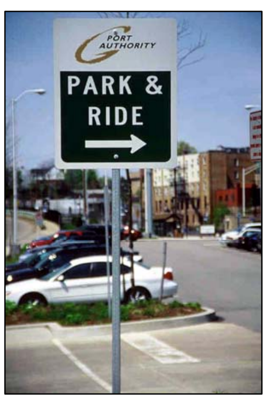
Description	Photograph
Station – Designated MAX station Las Vegas, NV	
Station – Designated MAX station Las Vegas, NV	
Station – Designated MAX Station Las Vegas, NV	
Station – Designated MAX station with Ticket Vending Machine and Beverage Vending Las Vegas, NV	

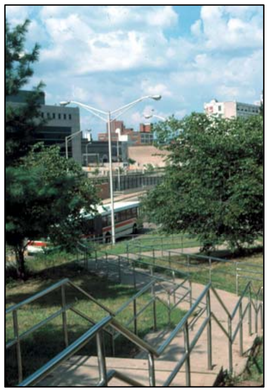
Description	Photograph
Station – Enhanced and modular station architecture Los Angeles Metro Rapid	
Station – Enhanced and modular station architecture of Los Angeles Metro Rapid	
Station – Intermodal station at Dadeland South station for transfers from the South Busway to Metrorail in Miami-Dade, Florida	
Station – Intermodal Terminal or Transit Center Ottawa Busway Intermodal Station	

Description	Photograph
Station – Level Boarding Interface at station, Leeds, England	
Station – LYMMO, Orlando, FL	
Station – Off-the-shelf station shelter in Oakland, CA	
Station – Platform Layouts - Extended Platform with Un-Assigned Berths Vancouver 98-B Line Station	

Description	Photograph
Station – Standard curbs as station platform	
Station – Raised Curb to facilitate passenger loading	
Station – Seating	
Station – Shelter at Rapid Bus Station, Oakland, CA	

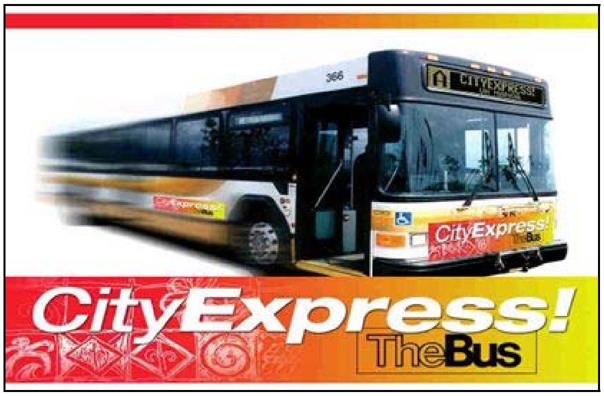
Description	Photograph
Station – Signage, MAX station, Las Vegas, NV	
Station – South Busway station Miami-Dade, FL	
Station – South Busway station Miami-Dade, FL	
Station – Station for San Pablo Rapid Bus AC Transit	

Description	Photograph
Station – Station Shelter along Washington Street, Silver Line Phase I, Boston, MA	
Station – Unified design for shelter and passenger information AC Transit	
Station – Designated Station Vancouver 98-B	
Station Access – Park-and-Ride Facility Park-and-Ride Lot, Pittsburgh Port Authority of Allegheny County	

Description	Photograph
Station Access – Pedestrian Linkages Walkway to Station Pittsburgh Port Authority of Allegheny County	
Station Vehicle – Vehicle at Busway Station Miami-Dade, FL	
Stations and Vehicles – A Low Floor Vehicle meeting the Level Boarding Platform for Prcision Docking	
Vehicle Configurations – Articulated vehicle (Van Hool)	

Description	Photograph
Vehicle Configurations – Civis Vehicle, Las Vegas, NV	
Vehicle Configurations – Conventional Articulated New Flyer DE60LF-BRT	
Vehicle Configurations – Conventional Articulated NEOPLAN AN460-LF	
Vehicle Configurations – Conventional Standard NABI 40 LFW Los Angeles Metro	

Description	Photograph
Vehicle Configurations - Invero	
Vehicle Configurations - SIlver Line Articulated CNG vehicle, Boston, MA	
Vehicle Configurations - Specialized BRT Vehicles Civis Vehicle, Las Vegas, NV	
Vehicle Configurations – Stylized Articulated NABI 60 foot BRT CNG Rendering 3 door	

Description	Photograph
Vehicle Configurations – Stylized Standard NABI Compobus 45C-LFW	
Vehicle Configurations - VanHool	
Vehicle – Closeup of vehicle following Optical Guidance Markers on a test track in Las Vegas	
Vehicle – Brand Identity Honolulu, HI	

Description	Photograph
Vehicle – Propulsion Systems MBTA Pilot Dual-Mode Articulated (Neoplan)	
Vehicle – Route Information on the Headsign and the Optical Guidance Scanner on the top of the vehicle	
Vehicle – Advertising Paint Scheme on rear of vehicle, Vancouver, Canada	
Vehicle – Automatic Vehicle Location Transponders	

Description	Photograph
Vehicle – Civis by Irisbus operating in Las Vegas	
Vehicle - Coimbra open door on square	
Vehicle – Driver Interfaces for Optical Guidance	
Vehicle – Livery (Paint Scheme), LYMMO, Orlando	

Description	Photograph
Vehicle – Livery (Paint Scheme), Vancouver, Canada	
Vehicle – New Flyer Hybrid Bus in Honolulu, HI	
Vehicle – Passenger Circulation, Alternative Seat Layout	
Vehicle – Rapid Bus Vehicle Oakland, CA	

Description	Photograph
Vehicle – Trolley Bus Articulated	
Vehicle – Wide doors on local circulator shuttle Coimbra, Portugal	
Vehicle – Wide doors that open parallel to the vehicle body	
Vehicle Asthetic Enhancements – Larger Windows and Enhanced Lighting	

Description	Photograph
Vehicle Asthetic Enhancements – Larger Windows and Enhanced Lighting	
Vehicle Asthetic Enhancements – Specialized Logos and Livery	
Vehicle Passenger Circulation - Additional Door Channels Van Hool	
Vehicle Passenger Circulation - Enhanced Wheelchair Securement	

Description	Photograph
Vehicle Propulsion Systems – MBTA Electric Trolley Bus (Neoplan)	
Vehicle Propulsion Systems – Fuel Cells	
Vehicle Propulsion Systems – Hybrid-Electric Drives	
Vehicle Propulsion Systems – Hybrid-Electric Drives	

Description	Photograph
Vehicle Propulsion Systems – Trolley, Dual Mode and Thermal-Electric Drives	
Vehicles – Emission Control Diesel (Neoplan) Boston, MA MBTA	
Vehicles – Miami-Dade Transit vehicle livery (paint scheme)	
Vehicles – Propulsion Electric Trolley Bus (Neoplan) Boston, MA MBTA	

Description	Photograph
Vehicles – Propulsion Systems MBTA Pilot Dual-Mode Articulated (Neoplan)	
Fare Collection – Barrier Enforced Fare Payment system	
Fare Collection – Barrier-Free (self-service) or Proof-of-Payment (POP) system	
Fare Collection – Barrier-Free (self-service) or Proof-of-Payment (POP) system MAX station, Las Vegas, NV	

Description	Photograph
Fare Collection – Barrier-Free (self-service) or Proof-of-Payment (POP) system MAX station, Las Vegas, NV	
Fare Collection – Barrier-Free (self-service) or Proof-of-Payment (POP) system MAX station, Las Vegas, NV	
Fare Collection – Hand-held Validator for Fare Inspection	
Fare Collection – Magnetic Stripe Media.	

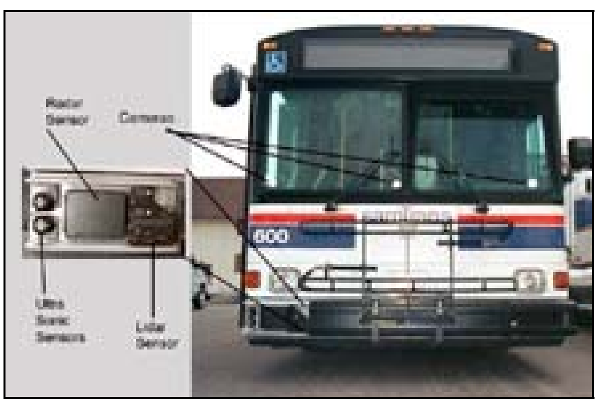
Description	Photograph
Fare Collection – On-Board Fare Collection in Conventional Bus in Curitiba, Brazil	
Fare Collection – On-Board Fare Inspector	
Fare Collection – Pay on-board system	
Fare Collection – Smart Card	

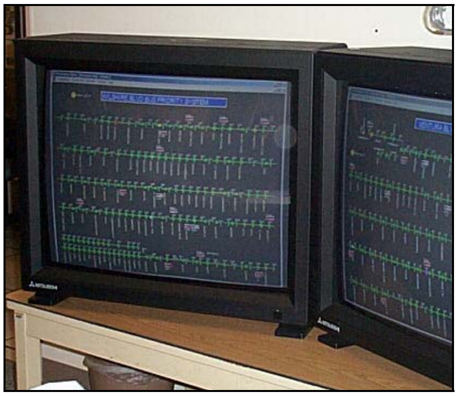
Description	Photograph
Fare Collection – Smart Card and on-board fare validator	
Fare Collection – Smart Card on a ticket vending machine (TVM) target	
Fare Collection – Smart Card on a validator	
Fare Collection – Smart Card on an on-board validator	

Description	Photograph
Fare Collection – Ticket Vending Machine as applied on a light rail system	
Fare Collection – Ticket Vending Machines and Passenger Information	
ITS – Embedded Loops in Roadbed for Vehicle Tracking	
ITS – Embedded Loops in Roadbed for Vehicle Tracking	

Description	Photograph
ITS – Operations Control Center for South East Busway in Brisbane, Australia	
ITS – Operations Maintenance, Vehicle Mechanical Monitoring and Maintenance	
ITS – Precision Docking	
ITS – Real-Time Passenger Information	

Description	Photograph
ITS – Real-time Passenger Information at Metro Rapid stations in Los Angeles	
ITS – Real-Time Passenger Information at Stations	
ITS – Real-Time Passenger Information at Stations	
ITS – Safety and Security, Emergency Telephone for Connection to Control Center	

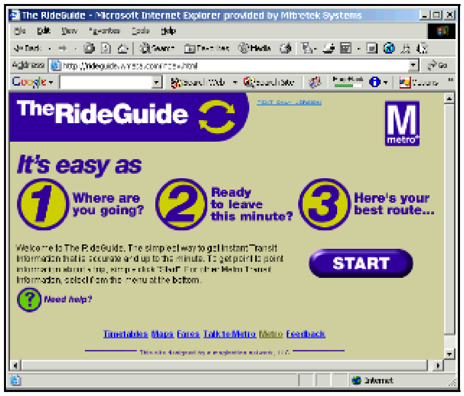
Description	Photograph
ITS – Safety and Security, Silent Alarms	
ITS – Safety and Security, Surveillance Camera for Security Monitoring, South East Busway, Brisbane Australia	
ITS – Sensor for Collision Warning	
ITS – Sensor for Collision Warning	

Description	Photograph
ITS – Support Technologies, Advanced Communication System	
ITS – Support Technologies, Passenger Counter	
ITS – Vehicle Operations Control Center Monitor for Vehicle Tracking from Transponder Readings	
ITS – Vehicle Prioritization, Station and Lane Access Control	

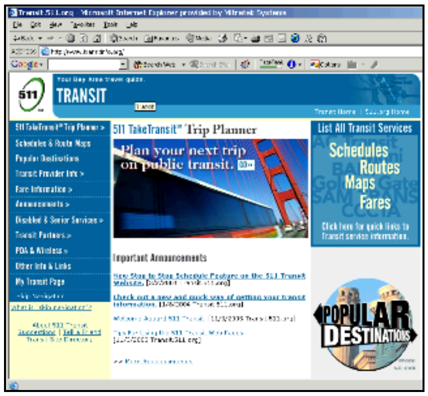
Description	Photograph
ITS – Vehicle Prioritization, Transit Signal Priority	
ITS – Vehicle Tracking for AVL	
ITS – Vehicle Tracking with Closed Circuit Television cameras	
ITS – Vehicle Transponder for Vehicle Tracking, Metro Rapid in Los Angeles	

Description	Photograph

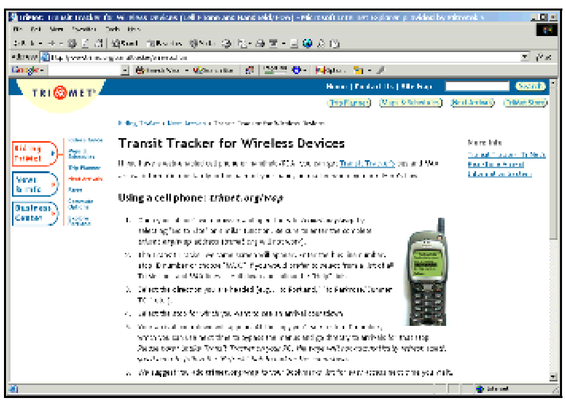
ITS – Web-Based Passenger Information for Trip Planning



ITS – Web-based Passenger Information Interface



ITS –Passenger Information on Person (for Mobile Devices)



ITS –Passenger Information on the Vehicle

Description	Photograph
ITS –Passenger Information on the Vehicle	
ITS –Passenger Information, Traveler Information at Stations	
Passenger Information sign for a multiple route network	
Passenger Information sign for a multiple route network	

Description	Photograph
Passenger Information sign in Vehicle	
Transit-Supportive Development – Pittsburgh, PA