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**SILVER LINE WATERFRONT BUS RAPID TRANSIT (BRT)  
2007 PROJECT EVALUATION • BOSTON, MASSACHUSETTS**

**JUNE 1, 2007**

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**PROJECT # DC26-7248-2007.02**

**SILVER LINE WATERFRONT  
BUS RAPID TRANSIT (BRT) PROJECT  
2007 EVALUATION**

A&E Services  
For Bus Rapid Transit Initiative  
Contract No. DTFT60-02-D-00009

Evaluation Report  
Silver Line Waterfront  
Boston, Massachusetts

Prepared by  
Washington Group International, Inc  
Wilbur Smith Associates

**JUNE 1, 2007**



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## FOREWORD

The U.S. Department of Transportation's Federal Transit Administration (FTA) is conducting a series of case study evaluations of a number of Bus Rapid Transit (BRT) systems that comprise the National BRT Consortium. The Massachusetts Bay Transportation Authority's Silver Line is one of these projects. The first phase of the Silver Line, on Washington Street, was the subject of an earlier evaluation report. The second phase, Silver Line Waterfront, was implemented with the goal of providing new transit service to South Boston's Waterfront area and new service to Logan Airport. This report presents an evaluation of the Silver Line Waterfront.

**The Silver Line Waterfront is one of a number of national BRT projects that make up the BRT Consortium**

Washington Group International and Wilbur Smith Associates – international planning and engineering firms – prepared this 2007 evaluation under contract to and with guidance from the FTA Office of Mobility Innovation. The evaluation is based on the *Guidelines for the Evaluation of BRT Demonstration Projects*, developed by the Volpe National Transportation Systems Center.

The FTA is evaluating projects in the National BRT Consortium to address the significant issues associated with the implementation and operation of BRT service. Sharing of this information with a broad audience of federal, state and local transportation agencies and consultants will greatly assist planners as they look to evaluate new transit options for their communities.

This evaluation is intended to assist transportation providers in developing projects to provide improved passenger services. Rapid Transit systems have historically been rail based, however recently there is interest in rubber-tired vehicles that operate similar to rail but at a lower cost. Information from this and other reports provide information including lessons learned for planners, engineers, operators and others involved in selecting transportation alternatives and implementing new or enhanced services.

This is a stand-alone report based on information from an initial operating period. It is recommended that it be used together with evaluations of other rapid transit facilities, in conjunction with the many documents available on BRT, other transit systems, their features and implementation.



## **ACKNOWLEDGMENTS**

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## **EXECUTIVE SUMMARY**

### **EXECUTIVE SUMMARY**

The introduction of the Silver Line Waterfront Rapid Transit service in Boston represents a new branch of rapid transit service to the South Boston waterfront and Logan International Airport. The Silver Line BRT System is one of a number of BRT projects that comprise the Federal Transit Administration's (FTA) BRT Consortium. It is being implemented in three phases. Phase I, the Washington Street service, began in July 2002 and provides service from Dudley Square to Downtown Crossing. Phase II, the subject of this report, is the Waterfront Line and features dual-mode (electric and diesel) vehicles. These operate on an exclusive right-of-way through a one-mile transit way in a tunnel connecting Boston's South Station transportation hub to the rapidly developing South Boston Waterfront district. Phase II service was also extended to Logan Airport, making it the first one-seat rapid transit ride from South Station to the various airport terminals. Phase III will connect the Washington Street service to South Station. The Silver Line system includes most of the elements of BRT presented in FTA's *Characteristics of Bus Rapid Transit for Decision Making* (CBRT) document published in August 2004.

#### **Evaluation of Silver Line Washington Street, 2005**

The first FTA-sponsored evaluation of the new Silver Line BRT system was completed in September 2005 and focused on the Silver Line Washington Street – an arterial BRT system. It showed that implementation of the first segment of new Silver Line service was generally a big success. Ridership on the new system jumped 96%, compared to the previous Route 49 bus service it replaced. PM peak period travel times were cut by 25% compared to Route 49 service, and approximately two-thirds of riders surveyed rated the Silver Line service as excellent or above average in reliability.

#### **Evaluation of the Silver Line Waterfront System, 2007**

This evaluation focuses on the second segment of the Silver Line BRT System – known as the Silver Line Waterfront. Two routes (SL2 and SL3) to South Boston opened in December 2004 and the third line (SL1) to Logan Airport opened in June 2005. All routes include one mile of tunnel with electrified guideway, and feature a dual-mode articulated vehicle.

#### **Travel Time**

The scheduled trip time from South Station to Logan Airport (Silver Line Waterfront Route SL1) is 15 minutes; the return inbound trip is scheduled between 23-25 minutes. The actual average running time for outbound trips is nearly at or slightly



## **EXECUTIVE SUMMARY**

below the scheduled running time nearly every hour of the service. This supports the relatively high marks the service receives from riders for its reliability.

### **Ridership**

The introduction of Silver Line Waterfront service to Logan Airport led to an initial 24% increase in overall public transit ridership to the airport, even taking into account riders who previously used the Blue Line service but switched to the more direct Waterfront service. Transit ridership to the Waterfront area increased by nearly 100% over the previous conventional bus and private shuttle service to the area. Of these new riders, more than 12% previously drove cars to the Waterfront. Nearly 40% of the riders are new – a reflection of the ongoing growth in development that is occurring in South Boston.

### **Land Use - Transit Oriented Development Impacts**

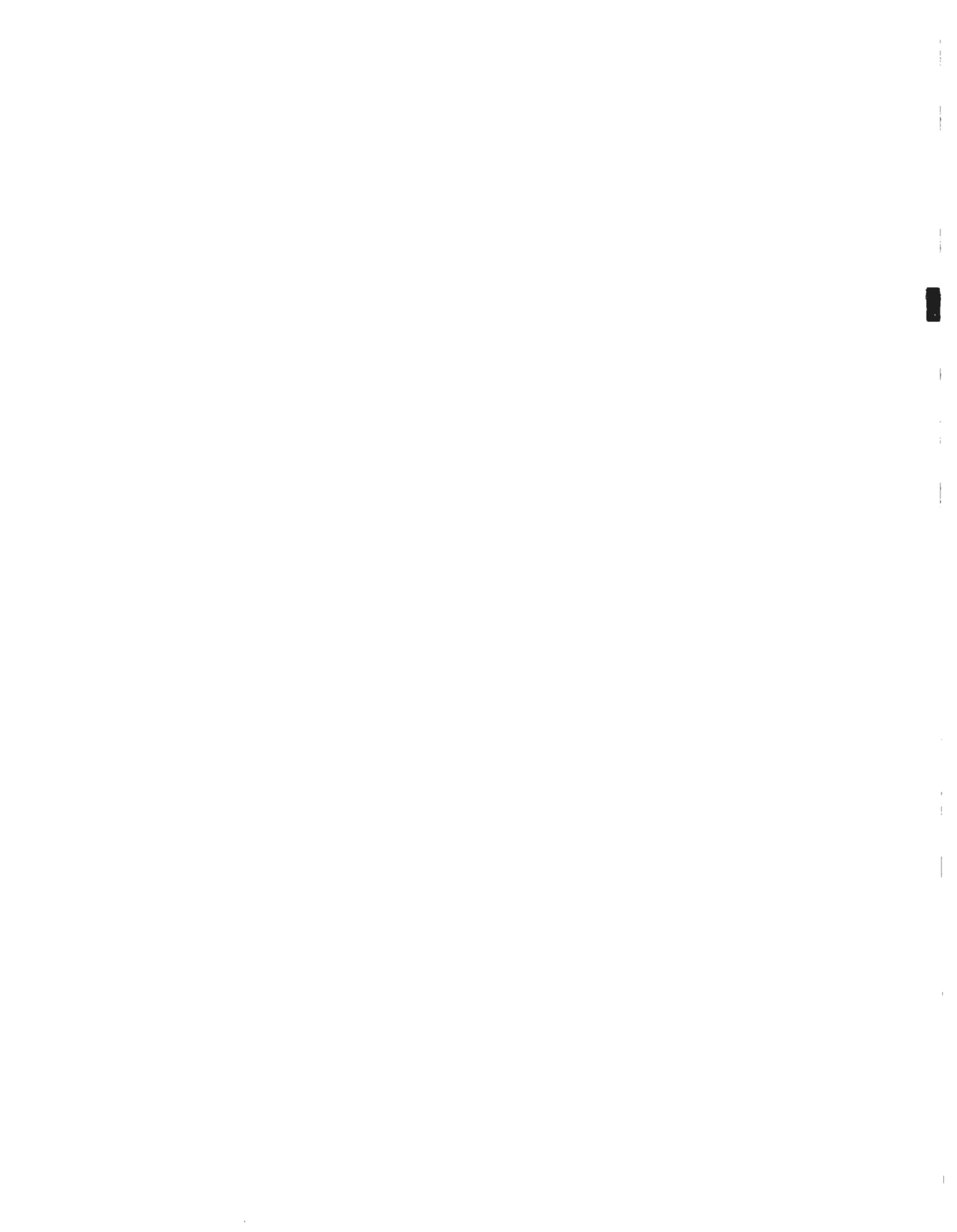
Nearly four million square feet of new development was opened for use in the South Boston Waterfront area between 1998 and 2006, the last few years of Silver Line construction and first few years of service. While no direct link between new development and the Silver Line can be proven, planners should take note of the relationship between land use and BRT service in South Boston, particularly as development continues.

As of June 2007 (the publication of this report), nearly 9 million square feet of additional development was planned for South Boston within a half-mile of the Silver Line Waterfront line. In addition, a major office tower is planned at South Station (which is served not only by the Silver Line but also by the Red Line subway, several commuter rail lines, and numerous regional and intercity buses). Station-area development closely linked to the Silver Line station entrances is planned for all of the other trunk line stations: Courthouse, World Trade Center, and Silver Line Way.

### **Transit Image and Public Perception**

The Silver Line Waterfront service provides a new identity and image for bus service in Boston. Most Silver Line riders surveyed give it high ratings for service quality. The public can find the Silver Line on the MBTA subway system map (along with the Red, Blue, Green and Orange rail lines), the service has a high degree of passenger information available, and it integrates well with existing MBTA rapid transit and commuter rail services at South Station.

In a 2006 survey of Silver Line Waterfront riders conducted by the Central Transportation Planning Staff (CTPS) for the MBTA, nearly 80% rated the safety,





## **EXECUTIVE SUMMARY**

travel time and directness of the Silver Line Waterfront service as above average or excellent. Nearly 90% rated the cleanliness of the Waterfront vehicles as above average or excellent, and nearly 70% ranked reliability of the service as above average or excellent. These results support many of the concepts introduced in the *FTA's Characteristics of Bus Rapid Transit for Decision Making* document, which cites reduced travel times, improved vehicle and station comfort, cleanliness and safety as key improvements of BRT over conventional bus service.

### **High Quality BRT Stations**

The Silver Line Waterfront features three large underground stations – at South Station, Courthouse and World Trade Center – with a finish quality equal to or better than other subway stations in the MBTA system. They are equipped with information booths, fare vending machines, waiting areas and route and system information.

### **Intelligent Transportation Systems (ITS)**

The Silver Line Waterfront uses several ITS components that are an integral part of daily operations and reflect key BRT elements. These include Automatic Vehicle Location and Automatic Fare Collection (begun in 2007). The three underground stations are equipped with LED signs that display schedule and other information. In addition, the tunnel portion of the system is equipped with a state-of-the-art automatic intrusion detection system to prevent unauthorized access.

### **Capital and Operating Costs**

The total estimated final capital cost of the Silver Line Waterfront system is approximately \$625 million. This includes approximately \$127 million for Russia Wharf tunnel, \$54 million for 32 dual-mode electric-diesel vehicles and \$110 million for the Courthouse Station & Tunnel. MBTA estimates the total operating cost for Silver Line Waterfront service is \$20,643 per weekday (Winter 2007 schedule).



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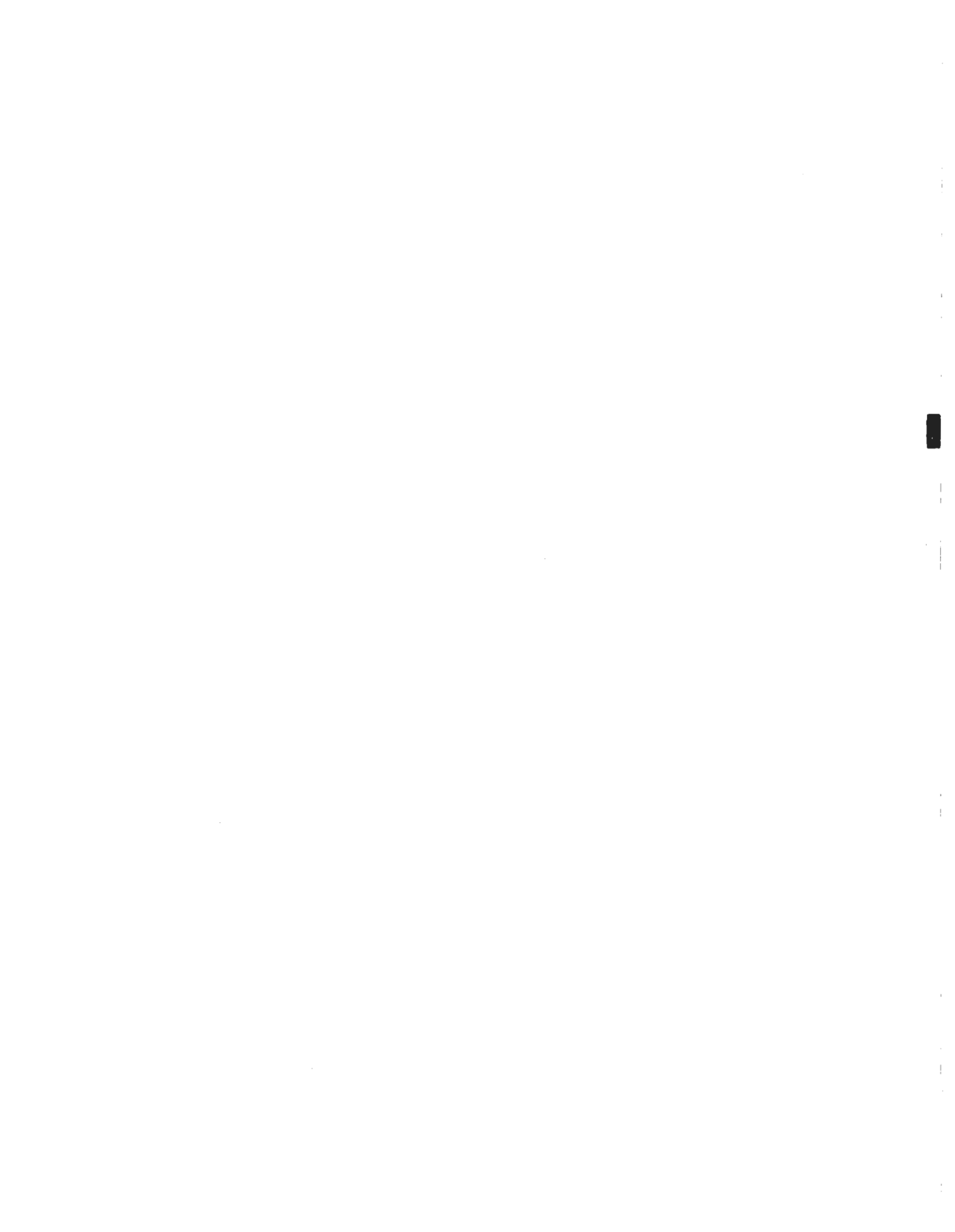
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## **1. INTRODUCTION**

### **1.0 INTRODUCTION**

#### **1.1 BACKGROUND**

The Federal Transit Administration's (FTA) Bus Rapid Transit (BRT) Initiative was designed to introduce the concept of Bus Rapid Transit to the U.S. transit industry by supporting the implementation, operation and evaluation of BRT services at a number of competitively selected sites. As a result of this effort, several U.S. cities have implemented BRT services and many others are either planning for, or considering, BRT as a transit option.

The FTA's BRT Initiative is now focused on continued development of guidance for the transit industry regarding the individual BRT elements and the range of impacts these elements have on ridership, costs, operating capacity, environment, economic development, and other aspects.

The Silver Line is one of a number of Bus Rapid Transit Demonstration Projects comprising the national BRT consortium. FTA is evaluating each of the consortium BRT projects to address the issues associated with the implementation and operation of Bus Rapid Transit service. Sharing of this information will greatly assist planners as they look to evaluate new transit options for their communities.

#### **1.2 EVALUATION OVERVIEW**

This evaluation is based on Evaluation Guidelines for Bus Rapid Transit (BRT) Demonstration Projects published by the Volpe National Transportation Systems Center (VNTSC) for FTA in February 2002. While the Guidelines document establishes the methodology for evaluation, the specific elements that are the focus of this evaluation come from Characteristics of Bus Rapid Transit for Decision Making (CBRT), published by the FTA in August 2004.<sup>1</sup> The CBRT report provides planners and decision makers the basic information and data requirements necessary to successfully undertake an evaluation by identifying and categorizing the major elements of BRT, their relationship to BRT system performance and the resulting system benefits.

This report follows a previous report prepared for the Federal Transit Administration, Boston Silver Line Washington Street Bus Rapid Transit (BRT) Demonstration Project Evaluation, FTA-VA-26-7222-2005, completed in September 2005.

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*1 Evaluation Guidelines for BRT Demonstration Project is available at: [http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS\\_TE/13831\\_files/13831.pdf](http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13831_files/13831.pdf); CBRT report is available at <http://www.qobrt.org/CBRT-DecisionMaking.pdf>*





## **1. INTRODUCTION**

The Silver Line Washington Street, opened for service in 2002, was Phase I of the Silver Line. The current evaluation focuses on Phase II, Silver Line Waterfront, opened in late 2004. The MBTA is seeking funding for a proposed Phase III to link the two. Phase I and Phase II have different funding sources, use different vehicle technologies, and have different types of rights-of-way, and began operations in different years. For all these reasons, it is appropriate to evaluate the phases separately. However, we will occasionally refer to Phase I (Washington Street) in this report.



## **2. PROJECT ELEMENTS**

### **2.0 PROJECT ELEMENTS**

The Silver Line is marketed as a new branch of “rapid transit” service in the Boston area, the first to use rubber-tire technology. The Silver Line includes each of the elements of a BRT system, as described in the *Characteristics of Bus Rapid Transit for Decision Making* published by FTA in August 2004. This section of the report provides a project and corridor description as well as a summary of each of the BRT elements.

#### **2.1 PROJECT SUMMARY**

Silver Line Phase I (Washington Street) opened in July 2002, providing service from Dudley Square to Downtown Crossing. Phase II (Waterfront), opened in December 2004, provides service from South Station to the South Boston waterfront. Service was expanded to Logan Airport in June 2005.<sup>2</sup> The proposed Phase III will connect the Washington Street service to South Station in a tunnel or at grade.

The Silver Line Waterfront operates three branch routes, SL1, SL2, and SL3. Between South Station and Silver Line Way, all three routes use a common Transitway that is in a tunnel except for a short ramp and at-grade section between World Trade Center station and Silver Line Way. All service in the Transitway operates on electric power using electric trolley wire. Some trips serve only the trunk route, ending at Silver Line Way. However, because the fleet consists of dual-mode (electric and diesel) vehicles that can switch to diesel power at Silver Line Way, other trips continue past Silver Line Way on three different branches. Route SL1 continues without any intermediate stops to the Logan Airport terminals. Routes SL2 and SL3 both serve the Boston Marine Industrial Park, but the latter continues to City Point (Figure 2-1). The MBTA has proposed a fourth branch, SL4, to serve the Convention Center and D Street, which may continue as far as Andrew Station on the Red Line.

Prior to the December 2004 start of service on the Silver Line Waterfront, the MBTA operated several local bus routes serving the area (routes 3, 4, 6, 7, and 11). In addition, several employers sponsored privately operated shuttle service between downtown Boston and the waterfront area. These routes were generally restricted to employees or those doing business with the sponsoring company.

Silver Line Waterfront opened in stages. From opening day on December 17, 2004 to December 30, 2004, service was only offered on the trunk route (South Station to Silver Line Way).

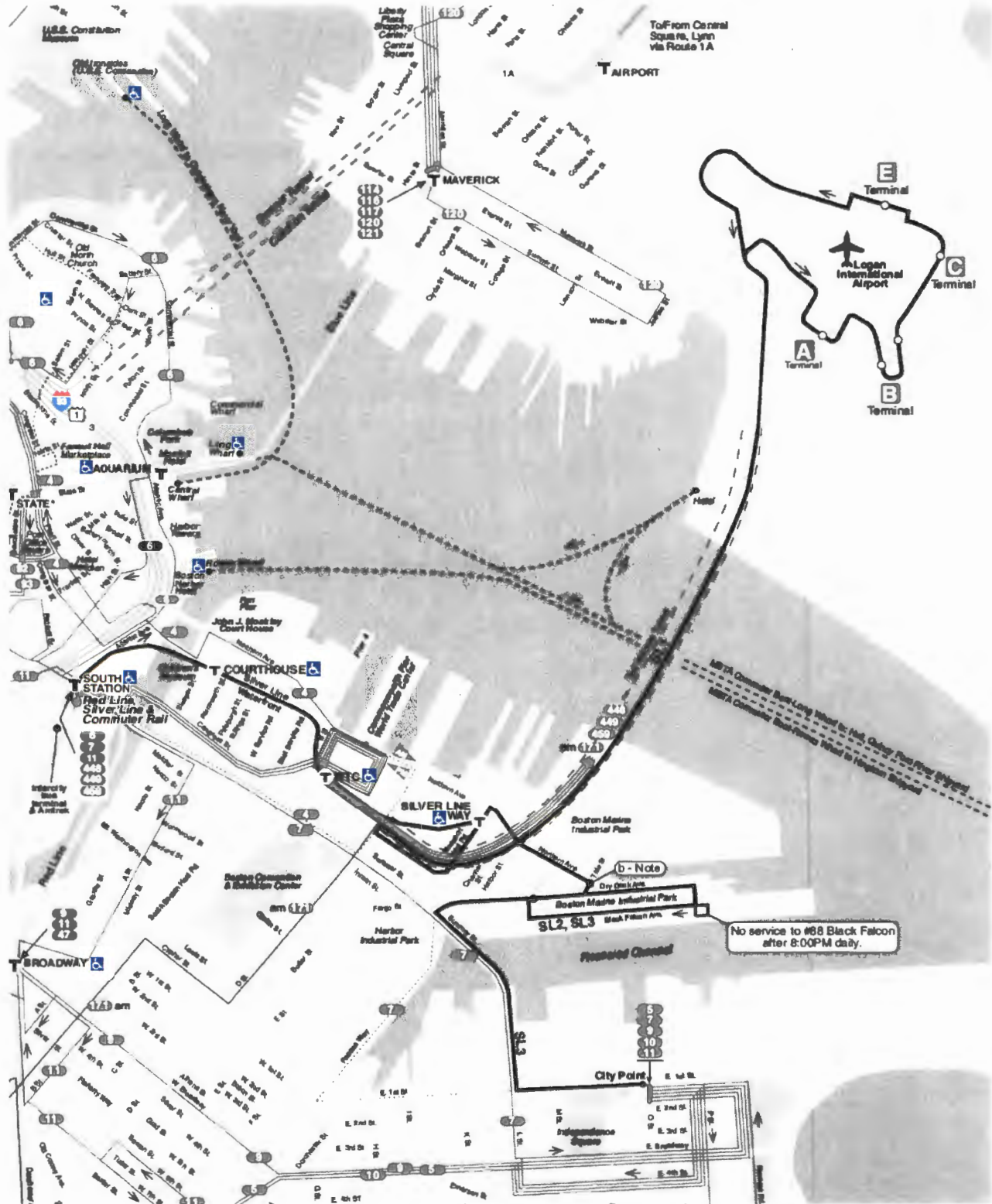
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<sup>2</sup>*Some Sunday service to the airport had been provided during the first six months of operation, but full service had to wait for the delivery of a sufficient number of dual-mode vehicles.*



## 2. PROJECT ELEMENTS

Figure 2-1: Silver Line Waterfront Routes SL1, SL2, and SL3





## 2. PROJECT ELEMENTS



**Figure 2-2: Switching to overhead wires at Silver Line Way (P. Schimek)**

Between December 31, 2004 and May 30, 2005, the trunk route and Silver Line Waterfront routes SL2 and SL3 were operated. The following changes to pre-existing MBTA routes in the area were made in January 2005:

- **Route 3:** Discontinued, partly replaced by Route 11 (see below).
- **Route 4:** Modified to operate via South Station toward North Station in the morning and toward World Trade Center in the evening. Between Post Office Square and World Trade Center, the route runs in a loop: in the morning peak, buses operate south from Post Office Sq. via Congress Street and Northern Ave to World Trade Center and return via D St., Summer St. (South Station), Atlantic Ave, Purchase St., and Pearl St. to Post Office Square. In the evening peak, buses operate from Post Office Square via Purchase St., Summer St. (South Station), D St. to World Trade Center, and return via Northern Ave., Purchase St., and Pearl St. to Post Office Sq. The segment between Post Office Square and North Station was not changed.
- **Route 6:** The segment from South Station to Boston Marine Industrial Park was eliminated. Service was maintained from Haymarket to South Station.



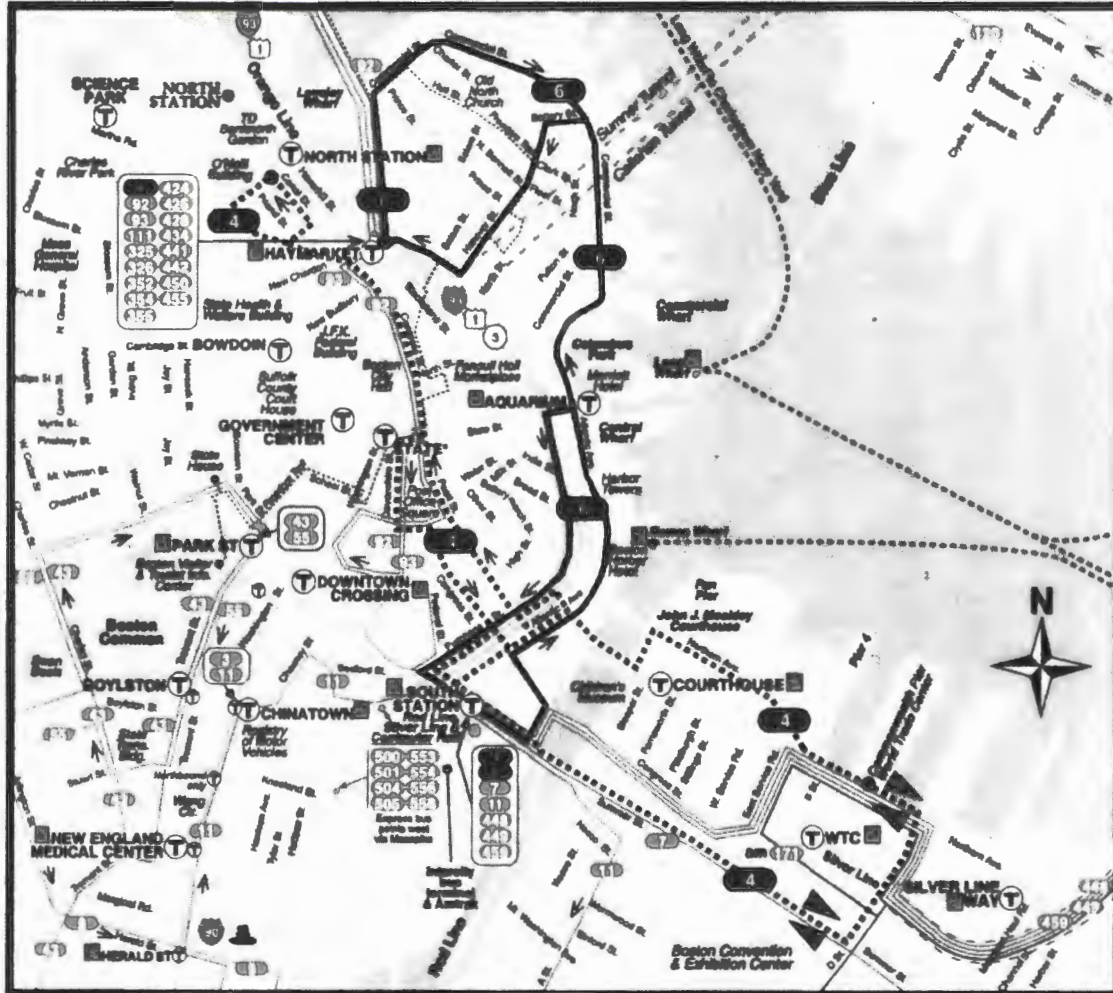


## 2. PROJECT ELEMENTS

Figure 2-3: Routes 4 and 6

**Ⓣ Route 4** North Station - World Trade Center via Congress St.

**Ⓣ Route 6** South Station - Haymarket Station via North End



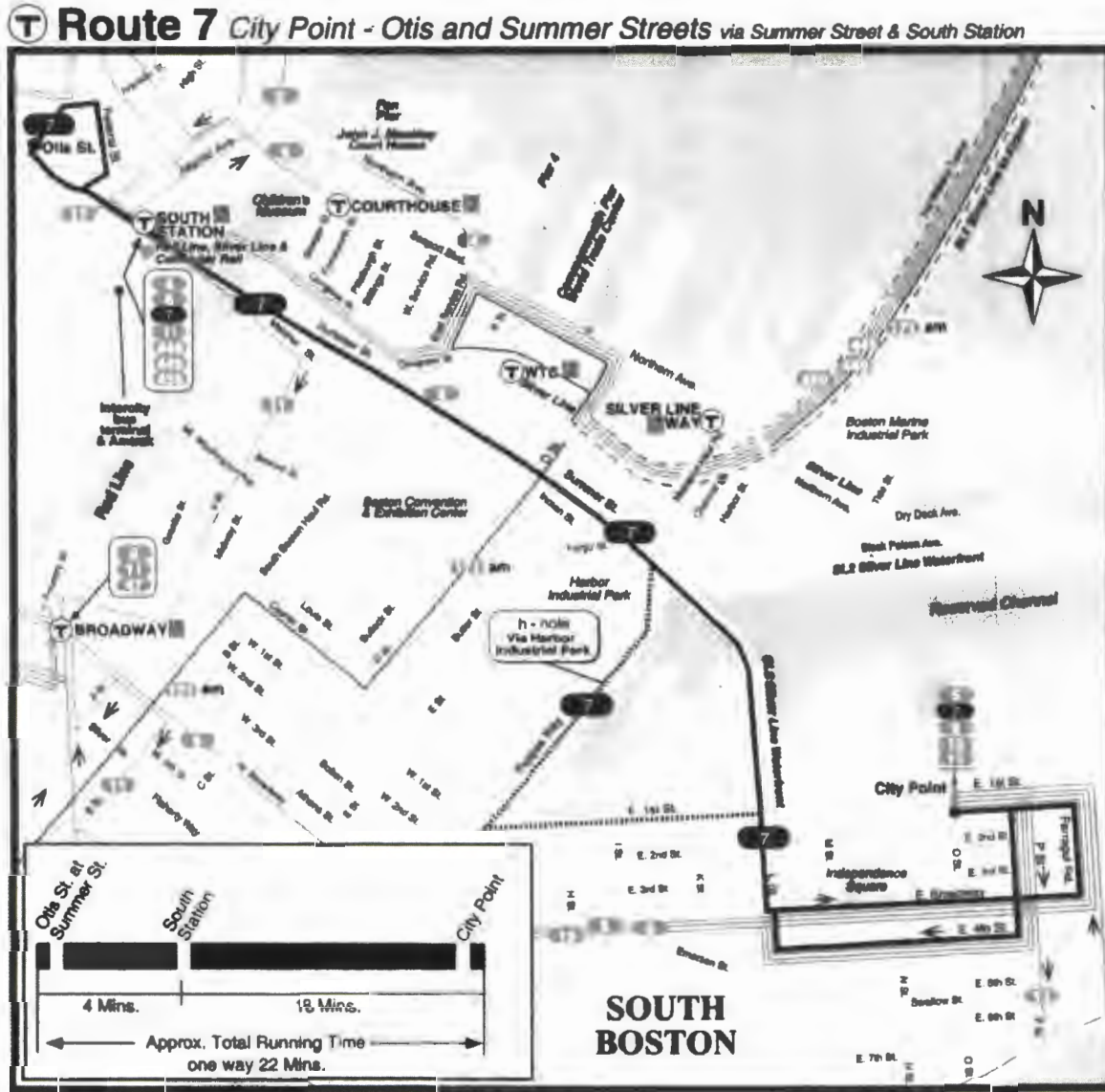
Map courtesy of MBTA

- **Route 7:** All service began operating direct via Summer St. Service via Northern Ave and Boston Marine Industrial Park was discontinued. Peak hour service was maintained to Harbor Industrial park outbound (away from Downtown) in the morning and inbound (to Downtown) in the evening. This routing is more direct, providing an additional benefit to those commuting to or from South Boston.



## 2. PROJECT ELEMENTS

Figure 2-4: Route 7



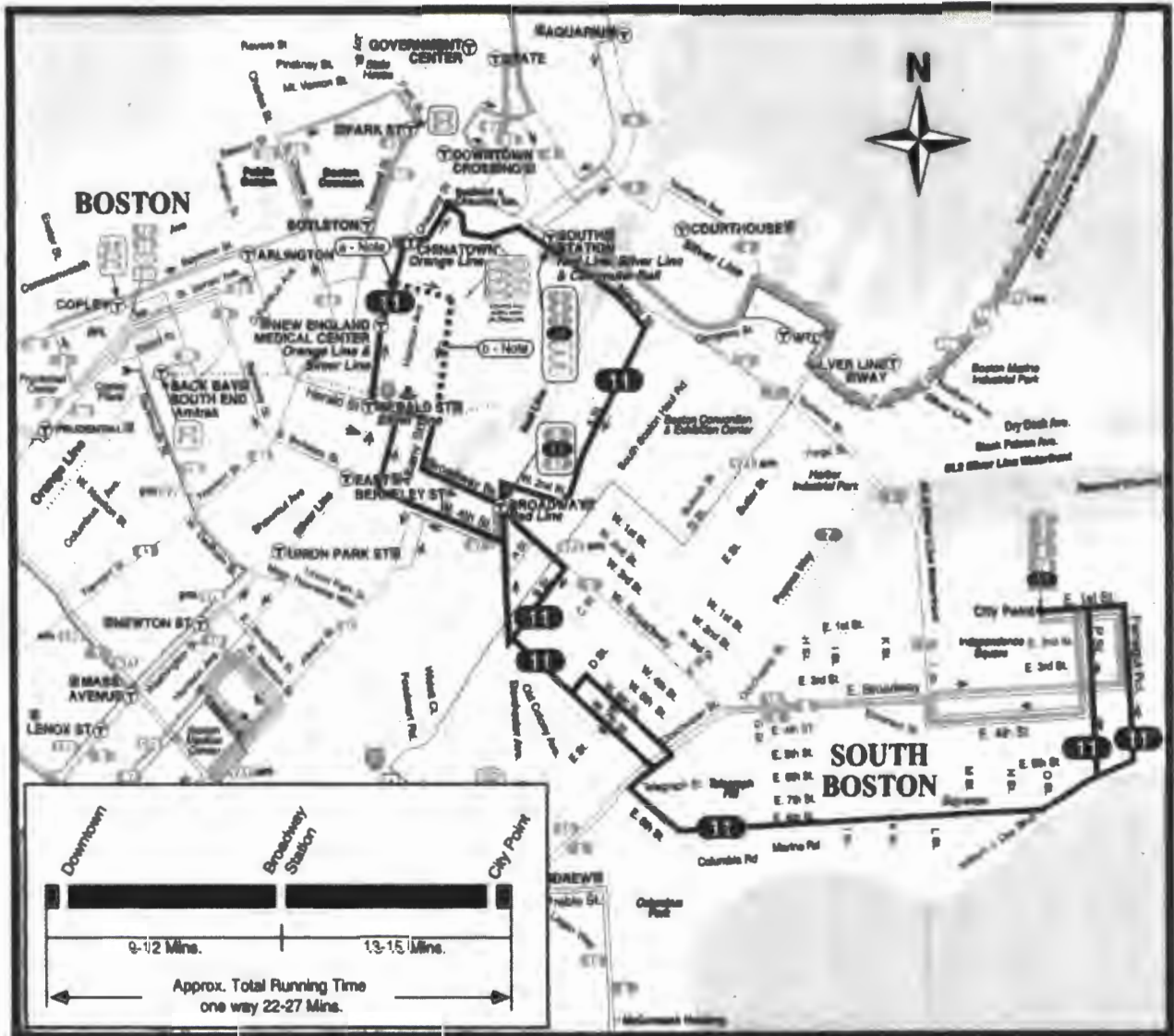
- Route 11:** The outbound routing changed between Bedford St. and Broadway Station to operate via Essex St., Atlantic Ave., Melcher St., A St., West Second, and Dorchester Ave, replacing a portion of Route 3. Late evening Route 11 service continues to operate only as far as Kneeland St and Washington St.



## 2. PROJECT ELEMENTS

Figure 2-5: Route 11

### **T** Route 11 *City Point - Downtown via Bayview*



Map courtesy of MBTA

On June 1, 2005, all-week service on route SL1 began, providing direct service to Logan Airport. A fourth route, SL4 to the Convention Center via D Street, has been discussed but not implemented.

In July 2006, a portion of the ceiling of the I-90 tunnel collapsed, killing a woman traveling in a car below. This event led to the closure of several ramps, including those providing entrance to the Ted Williams Tunnel. The MBTA started using the emergency onramp to the Ted Williams Tunnel during the morning peak, just a few hours after the collapse occurred. The T got permission from



## 2. PROJECT ELEMENTS

the Massachusetts Turnpike Authority to use an on-ramp near Silver Line Way, leading to the I-90 eastbound tunnel. See section 2.8 for more information about the response to the tunnel collapse.

### 2.2 RUNNING WAYS

The trunk portion of the Silver Line Waterfront operates on an exclusive right-of-way of approximately 1 mile, almost all of which is in a tunnel. The remainder of the Waterfront routes operate in mixed traffic in city streets and, in the case of Route SL1, on the Ted Williams Tunnel, which is part of the expressway system, and Logan Airport terminal roadways.



**Figure 2-6: Silver Line vehicle in tunnel section (MBTA)**





## 2. PROJECT ELEMENTS

### 2.3 STATIONS

The Silver Line Transitway tunnel has three underground stations: South Station, Courthouse, and World Trade Center. These have information booths, fare vending machines, waiting areas, and route and system information. Each of the stations has their own design and layout. The Courthouse and World Trade Center stations, and also Silver Line Way, the single surface stop shared by all routes, are planned to have direct access to future development built immediately above or adjacent to the tunnel. Most surface stops have shelters installed and maintained by Wall USA; these include an MBTA system map. All surface stops have silver-colored route signs. The stops at the Logan Airport terminals are located at the far end of each terminal pick-up area and are sheltered and have passenger information. The fare vending machines for four of these stops are located in the baggage claim area, so passengers can get a ticket while waiting for their luggage. The fare vending machines for the remaining stop, Terminal C, is located on the curb near the stop itself.



Figure 2-7: Interior, Courthouse Station (MBTA)



## 2. PROJECT ELEMENTS

### 2.4 VEHICLES

The tunnel was designed for use by electric vehicles. The MBTA originally planned to use electric trolleybuses running on trolley wire only. Due to community opposition to hanging wire on public streets (for use by routes extending beyond the Transitway), the MBTA decided to purchase dual-mode buses. Neoplan was able to create a custom-order articulated low-floor bus with an electric motor powered either by electric trolley wire or by a diesel generator. The MBTA took delivery of 32 of these vehicles between 2004 and 2005. Twenty-four are for general use and have 47 seats with a stated capacity of 96 passengers. However, a Massachusetts regulation limits bus occupancy to 140% of the number of seats, meaning 65 passengers for a bus with 47 seats.<sup>3</sup> Buses designed for airport service, paid for by the Massachusetts Port Authority, have 38 seats and luggage racks.



**Figure 2-8: Silver Line Vehicle at Logan Airport (MBTA)**

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<sup>3</sup>220 Code of Massachusetts Regulations Section 550.02 (26) reads: For a bus longer than 23 feet, "Passengers in excess of 40 percent above the seating capacity of a motor bus shall not habitually be carried . . . Where the number of passengers regularly exceeds these excess numbers of passengers, it shall be the duty of the owner to furnish additional vehicles to carry such passengers." Source: <http://www.mass.gov/Eoca/docs/dte/cmr/220cmr155.pdf>, accessed April 23, 2007.



## 2. PROJECT ELEMENTS

### 2.5 FARE COLLECTION

The three belowground stations on the Silver Line Waterfront have barrier fare collection using gates. For the surface stations, fare is paid at the farebox near the bus driver. The bus driver is responsible for monitoring fare payment. Boardings at surface stops are permitted from the front door only. The MBTA completed installation of automatic fare collection (AFC) gates on the Silver Line Waterfront belowground stations in February 2006. Silver Line Waterfront fareboxes (for surface stops) were converted in May 2006. Fare vending machines were installed near Silver Line stops at Logan Airport in November 2006. Smart cards became available for use on the Silver Line and the rest of the MBTA system (except Commuter Rail and Boat) in December 2006.



Figure 2-9: Electronic farebox (P. Schimek)



## **2. PROJECT ELEMENTS**

### **2.6 INTELLIGENT TRANSPORTATION SYSTEMS**

The Silver Line includes the following Intelligent Transportation Systems (ITS) elements:

- Computer Aided Dispatch/Automated Vehicle Location (CAD/AVL) communications system designed to electronically communicate vehicle location. To compensate for lack of GPS reception in the Silver Line Tunnel and the Ted Williams Tunnel, all vehicles are equipped with dead-reckoning units.
- On-board public address and variable message sign passenger information display, which announces all stops.
- LED signs at South Station, Courthouse and World Trade Center providing schedule and general information.
- Computerized information kiosks at South Station, which include MBTA and Logan information.
- Automatic intrusion detection system to prevent unauthorized access to the tunnel, closed-circuit television systems, portal protection, and other, undisclosed security and anti-terrorism initiatives.

### **2.7 SERVICE AND OPERATIONS PLANS**

There are three branches of the Silver Line Waterfront, and a fourth has been proposed. All branches serve the trunk route from South Station to Silver Line Way. During the first year of service there were several modifications to the SL2 and SL3 surface routes. The opening of the Silver Line was accompanied by the elimination of one MBTA surface route and the modification of four others. All pre-existing privately operated shuttle bus routes operating between South Station and the South Boston Waterfront were eliminated.

When the SL1 first entered revenue service, it ran with six buses every 10 minutes on weekdays between 7am and 8pm, and four buses every 15 minutes in the evenings and on weekends. Two things soon became clear: the running time was faster than anticipated, and the evening and weekend demand was higher than anticipated. In October 2005, the schedule changed from six buses at a 10-minute headway to five buses at a 10-minute headway for most of the day, and in March 2006 service was changed to four buses at a 12-minute headway in the evenings and on weekends.

The MBTA adds airport service during the Thanksgiving and Christmas holiday seasons to meet the increased demand for airport service. In 2006, service was





## **2. PROJECT ELEMENTS**

run every 10 minutes instead of every 12 on the weekend before Thanksgiving, every 6 minutes instead of every 10 minutes on the weekdays leading up to Thanksgiving, and every 8 minutes instead of every 10 minutes on the Friday, Monday and Tuesday after Thanksgiving. The MBTA estimates that it carried 7,000 airport travelers each day on the two days before Thanksgiving, a 144% increase over typical daily airport ridership.

The MBTA also adds service to meet increased demand for South Boston Waterfront service during large conventions and special events. They are in communication with the Seaport TMA to learn when extra service will be necessary. On Saturday and Sunday, March 3<sup>rd</sup> and 4<sup>th</sup>, 2007, the visiting USS John F. Kennedy was docked at the Boston Marine Industrial Park and proved a popular attraction. The MBTA added eight buses each day, and estimates it carried 50,000 people over two days, five times its typical weekend ridership.

### **2.8 RESPONSE TO TED WILLIAMS CONNECTOR ACCIDENT**

In July 2006, a portion of the ceiling of the I-90 tunnel collapsed. This event led to the closure of several ramps, including those providing entrance to the Ted Williams Tunnel. Not only did this mean that the SL1 could not use its normal tunnel access, but it meant that half of the principal roadway access to New England's dominant airport was inaccessible to autos. Auto access was gradually restored over the next six months.

In cooperation with the State Police, as well as Massport, the Massachusetts Turnpike Authority, and the City of Boston, the MBTA started using an emergency vehicle access ramp to the Ted Williams Tunnel during the morning peak just a few hours after the collapse occurred. Police oversaw the use of the ramp. Buses were the only vehicles in the Ted Williams Tunnel eastbound, and shared a lane with emergency vehicles going westbound. To address the increased demand for transit at the airport, two buses were added, and the SL1 ran at an 8-minute headway instead of a 10-minute headway. The MBTA estimates that ridership to and from the airport jumped about 70% immediately after the tunnel collapse, and gradually returned to normal as portions of the highway were re-opened.



### **3. SYSTEM COSTS**

## **3.0 SYSTEM COSTS**

### **3.1 CAPITAL COSTS**

The capital costs of the Silver Line project, as of August 2006, are shown in Table 3-1. The final cost numbers are pending the outcome of several lawsuits between the MBTA and its contractors or between the MBTA and property owners affected by the project. The MBTA has budgeted a reserve account of \$25 million on top of the official \$600.92 million cost of the project. As of August, 2006, the estimated costs to complete the project was just short of the total budgeted amount, including the reserve account.

Because the contracts are not separated by type of project work (e.g., station or tunnel), it was impossible to get separate cost estimates for running ways and stations. Also complicating the cost accounting is the project-performed work that was reimbursed by other government agencies, private entities, or other parts of the MBTA capital budget. These are listed as reimbursements and shown in negative amounts in Table 3-1.

One of the largest contract amounts was the Russia Wharf tunnel. This contract was expensive because the project was required to dig under historic Russia Wharf without disturbing the old buildings above it. According to the MBTA, "Using pipes carrying a brine solution, workers cooled the soil to 5 degrees to freeze the ground below the structures. Following the soil-freezing procedure, crews built a system of continuous supports to minimize movement during boring." The plan called for placing tunnel sections underneath the Fort Point Channel. An unexpected problem was the discovery of a 33-ton boulder directly in the tunnel alignment underneath the Channel. An eight-ton chisel was ineffective to break up the rock; a hydraulic rock splitter was used instead. This problem delayed the project by about a year.

The three stations and their associated tunnel sections were the next largest cost elements. The Courthouse Station was the most elaborate and thus most expensive (\$109.9 million, plus land acquisition). This figure also includes a third lane for passing and 1450 linear feet of tunnel section. The South Station contract was \$96 million, including a turnaround loop and stub tunnel section for future expansion and 1550 linear feet of tunnel section. The World Trade Center station was the most modestly designed station, and was also the least expensive (\$43 million) including 1200 linear feet of tunnel section.



### 3. SYSTEM COSTS

**Table 3-1: Silver Line Waterfront Capital Costs**

|  | Cost to Complete* | Contracts        | Comments      |
|--|-------------------|------------------|---------------|
| South Station -- Station & Tunnel  | \$95.9            | CC01, CC15       | in litigation |
| Red Line Betterment Reimbursement  | \$-12.9           |                  |               |
| South Station Finishes   | \$12.8            | CC15A            |               |
| South Station Acquisition  | \$0.95            |                  |               |
| Congress St Tunnel Section (200 ft)  | \$4.5             | CC02A            |               |
| Russia Wharf Tunnel  | \$127.6           | CC03, CC05       | in litigation |
| Russia Wharf Acquisition   | \$12.3            |                  |               |
| Central Artery Project Reimbursement   | \$-28.7           |                  |               |
| Children's Museum Reimbursement  | \$-1.5            |                  |               |
| Russia Wharf to Courthouse Land Acquisition                                      | \$5.7             |                  |               |
| Courthouse Station & Tunnel  | \$109.9           | CC07, CC08, CC10 | in litigation |
| Courthouse Station Acquisition   | \$26.3            |                  |               |
| Seafood Center Fishery Coop Reimbursement  | \$-15.3           |                  |               |
| World Trade Center Station & Tunnel  | \$41.5            | CC09, CC11       |               |
| World Trade Center Acquisition (Massport)  | \$1.5             |                  | in litigation |
| Systems: Tunnel Lighting, Power, Catenary, Communications, Emergency Ventilation | \$38.1            | CC12, CC13, CC16 | includes fans |
| Interim Power  | \$3.5             |                  |               |
| Southampton St Maintenance Facility  | \$48.2            | CC14             |               |
| Southampton St Maintenance Facility CNG Cost                                     | \$-39.1           |                  |               |
| Southampton St Land Acquisition  | \$8.6             |                  | in litigation |
| Southampton St Land Acquisition CNG Cost   | \$-8.1            |                  |               |
| Dual Mode Vehicles (32)  | \$53.8            |                  |               |
| Procurement  | \$1.7             |                  |               |
| MassPort Reimbursement   | \$-13.3           |                  |               |
| Design Services**  | \$91.7            |                  |               |
| Force Account**  | \$2               |                  |               |
| Field Inspection**   | \$16.4            |                  |               |
| Project Administration**   | \$10.1            |                  |               |
| Indirect Overhead**  | \$11.3            |                  |               |
| General & Administrative Overhead**  | \$3               |                  |               |
| Owner Control Insurance Program  | \$15.7            |                  |               |
| <b>GRAND TOTAL</b>   | <b>\$624.2</b>    |                  |               |

\*COST TO COMPLETE as of August 26, 2006, values in millions of dollars.

\*\* Not including costs related to CNG buses (which is about 80% of total maintenance facility cost).



### 3. SYSTEM COSTS



Figure 3-1: Excavations for Silver Line tunnel at Russia Wharf (MBTA)

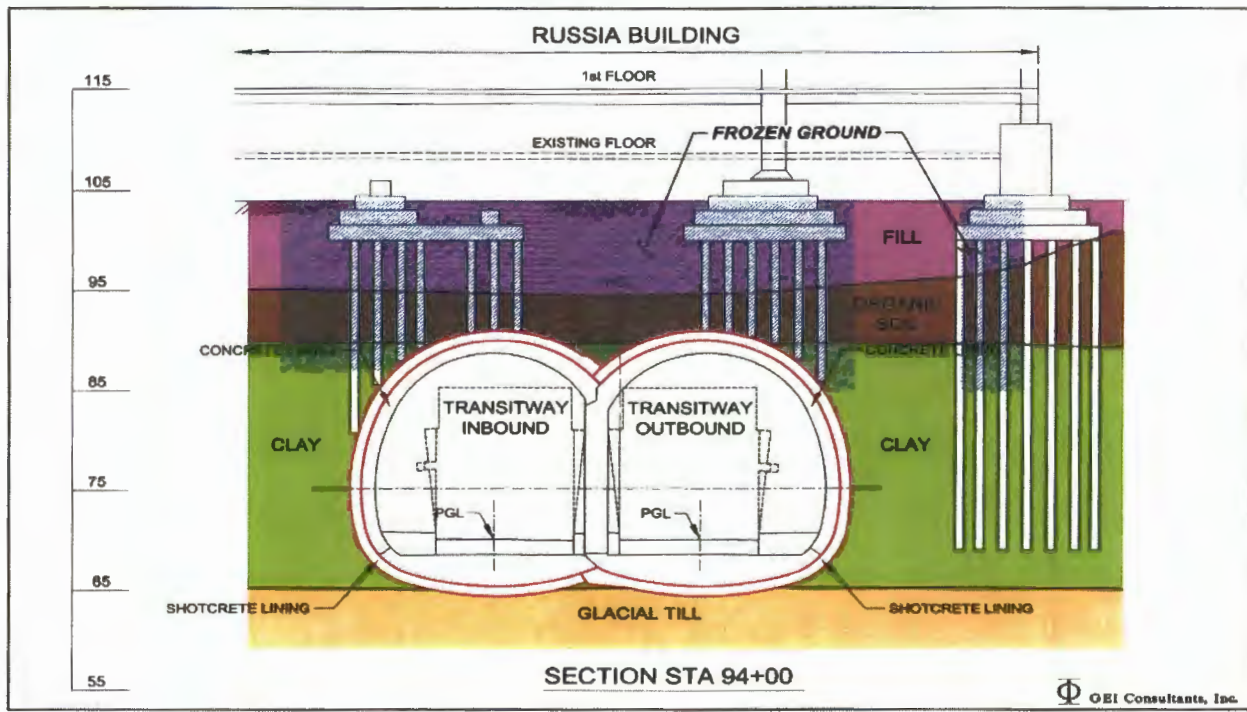


Figure 3-2: Russia Wharf construction details (GEI Consultants, Inc.)





### 3. SYSTEM COSTS



**Figure 3-3: Aerial view of Silver Line construction (MBTA)**

The new Southampton Street maintenance facility cost \$56.7 million for construction and acquisition (not including design costs), but about 80% of the cost was attributed to the CNG buses that share the facility, largely because of the additional safety requirements for using natural gas. (In the 2001 revised Full Funding Grant Agreement, discussed below, the CNG share was set at 60%. It is not clear why it changed in the final accounting.)

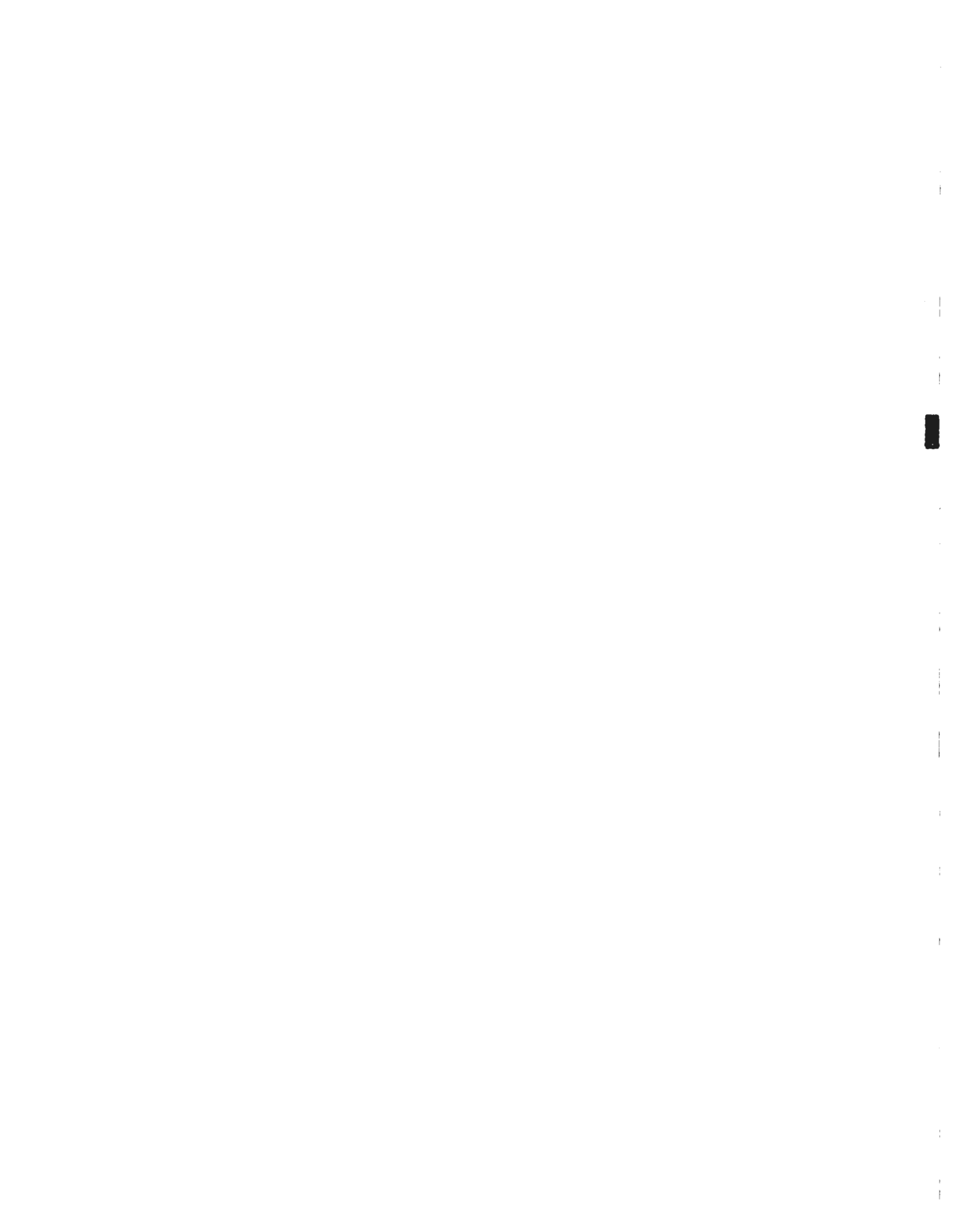
Another \$4.02 million, not included in Table 3-1, was expended under a different budget line for security enhancements. These include an automatic intrusion detection system to prevent unauthorized access to the new tunnel, closed-circuit television systems, portal protection, and undisclosed security and anti-terrorism initiatives.



### 3. SYSTEM COSTS



**Figure 3-4: Dual-mode vehicles at Southampton Street garage (P. Schimek)**



### 3. SYSTEM COSTS

#### Fare Vending Machines

Shortly before Thanksgiving 2006, the MBTA installed two fare vending machines (FVM), one full service and one cashless, at each Logan Airport terminal stop, except that Terminal C has only one full service FVM. The equipment is manufactured by Scheidt & Bachmann (a German company), who also provide parking ticket machines for Massport. The cost was \$23,420 per cashless machine and \$35,494 per full service machine, paid by MBTA. Construction and installation was \$275,000, paid by Massport. An additional \$593,000 (\$322,000 by Massport and \$271,000 by MBTA) was spent to install necessary infrastructure. The total cost of the FVM deployment at the airport was thus \$1.26 million, including equipment, infrastructure, and installation.



**Figure 3-5: Fare Vending Machines at Logan Airport (P. Schimek)**

In the month before installation, all MBTA customer service representatives at the airport were trained in the use of FVMs so that they could readily assist customers. The T reported no service problems during the first month of use, is satisfied with



### 3. SYSTEM COSTS

the equipment, and anticipates that the installation of FVMs will quickly pay for itself with more accurate fare collection and recording.

#### History of Project Cost Estimates

The project was listed in the 1991 ISTEAs legislation for \$278 million of Federal Funds. The Draft EIS cost estimate in 1992 was \$284 million. This estimate was increased for the Final EIS to \$345 million in 1993. When the Full Funding Grant Agreement was executed in 1994, the estimate rose to \$413 million and the project was estimated to open in 2000. There were several major construction delays. A revised FFGA in 2001 calculated the cost at \$600.9 million. In September 2005, the MBTA's cost to complete was calculated to be \$618.8 million. As of August 2006, the total project costs were \$624.2 million after some legal claims were settled. The MBTA still feels that the cost to complete for the project will be \$618.8 million when all legal claims are resolved. New Starts funds were initially planned to cover 80% of the cost. Due to cost increases, they are covering 53% of the cost; with the balance consisting of Federal formula funds (that could be used on any capital project) and MBTA bond proceeds.

**Table 3-2: History of capital cost estimates and funding sources, Silver Line Phase II, a/k/a South Boston Piers Transitway (year of estimate dollars)**

| Year of estimate                | 1991         | 1993         | 7/1/1993     | 6/1/2001     | 2001         |
|---------------------------------|--------------|--------------|--------------|--------------|--------------|
|                                 | DEIS         | FEIS         | FFGA         | Rev. FFGA    | Current      |
| Construction                    | 172.4        | 190.2        | 210.9        | 336.2        | 339.5        |
| Acquisition                     | 8.3          | 24           | 24.6         | 26.4         | 41.1         |
| Systems                         | 11.8         | 31.7         | 32.0         | 33.7         | 41.6         |
| Maintenance Facility            | 7.2          | 14.2         | 19.8         | 8.7          | 9.6          |
| Vehicles                        | 30.5         | 28.3         | 37.2         | 42.9         | 42.2         |
| Design & Engineering            | 20.6         | 26.7         | 38.5         | 87.3         | 91.7         |
| Overhead, Inspection, Insurance | 9.3          | 11.4         | 32.1         | 56.5         | 58.5         |
| Contingency                     | 24.1         | 17.6         | 18.2         | 9.3          | 0            |
| <b>TOTAL</b>                    | <b>284.1</b> | <b>344.6</b> | <b>413.4</b> | <b>600.9</b> | <b>624.2</b> |
| Federal New Starts funds        |              |              | 330.7        | 330.7        | 330.7        |
| Federal Formula funds           |              |              | 0.0          | 150.0        | 150.0        |
| Local share                     |              |              | 82.7         | 120.2        | 143.5        |
| <b>TOTAL</b>                    |              |              | <b>413.4</b> | <b>600.9</b> | <b>624.2</b> |





### **3. SYSTEM COSTS**

#### **3.2 OPERATING COST**

For service planning purposes, MBTA estimates that the operating cost for Silver Line Waterfront service is \$20,643 per weekday for the Winter 2007 schedule. This estimate is based on the average operating cost for standard bus service. It does not take into account the additional fuel and maintenance costs of operating an articulated, dual-mode vehicle. This amount bought 197 vehicle hours of service, of which 145 were scheduled revenue service hours and 52 were scheduled layover hours and very short deadheads.<sup>4</sup> The average cost per vehicle revenue hour is thus \$142. About \$2 million annually is provided by Massport to support the operating costs of the SL1 service.

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<sup>4</sup> According to the definitions used for the National Transit Database, vehicle revenue hours include layover or recovery time, but exclude deadhead time See <http://www.ntdprogram.com/ntdprogram/pubs/ARM/2003/html/2003%20GPRA.htm>



## **4. PLANNING, DESIGN AND IMPLEMENTATION**

### **4.0 PLANNING, DESIGN AND IMPLEMENTATION**

#### **4.1 PLANNING TIME LINE<sup>5</sup>**

The following is a time line of events in the planning and design of the Silver Line Phase II:

##### **Mid-1980s**

Industrial South Boston, adjacent to Downtown, is seen as the next frontier for real estate development as a building boom is underway. A developer proposes building a monorail or elevated people mover from downtown to the South Boston Piers area.

##### **1987**

The MBTA conducts a feasibility study for increasing transit service to the Piers area, including a wide variety of options and modes.

##### **1987-1989**

A Draft Environmental Impact Report (DEIR), required by Massachusetts environmental law, begins in the fall of 1987 and is circulated in the fall of 1989. Five action alternatives were analyzed: Bus/Transportation System Management (TSM), At-Grade Light Rail, Elevated People Mover, Fort Point Channel Underground Transitway, and Red Line Loop. The Underground Transitway using either trackless trolleys or dual mode buses was designated as the locally preferred alternative.

##### **1990-1992**

In August 1990, the Federal Transit Administration (FTA) approves the MBTA's application to advance the "South Boston Piers/Fort Point Channel Transit Project" into the Federal alternatives analysis/environmental impact statement (AA/DEIS) process in accordance with the National Environmental Policy Act (NEPA). Based on the analysis and results of the DEIR, only a subset of alternatives is required by FTA for analysis as part of the federal process. Given the two years that had lapsed since publication of the DEIR, the MBTA and MEPA Unit agree that the DEIS also will serve as a supplement to the earlier DEIR. The alternatives analyzed in the DEIS/SDEIR include a No Action Alternative, a Bus/TSM Alternative, and three variants of the Underground Transitway Alternative: a Full Build alignment from the existing Boylston Green Line Station to a new station at the World Trade Center in the Piers area; Minimum Operable Segment (MOS) 1, which extends from South

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<sup>5</sup> This section is based on the summary presented in the *Third Annual Update Pursuant to M.G.L. Section 61*, Cambridge Systematics, 2005.



## **4. PLANNING, DESIGN AND IMPLEMENTATION**

Station to the Fan Pier; and MOS-2 extending from South Station to the World Trade Center. The FTA approves the DEIS/SDEIR in November 1992.

### **1993**

On January 13, 1993, the Massachusetts Secretary of Environmental Affairs issues a Certificate finding the DEIS/SDEIR adequate and in compliance with the MEPA. The MBTA designates the Fort Point Channel Underground Transitway Full Build Transitway (also referred to as the South Boston Piers Full Build Transitway) as the locally preferred alternative. The Full Build Alternative was deemed the best solution to transportation problems in the Piers area. This was measured in terms of improved transit service to the Piers area; support of future economic expansion in the Piers area; mitigation of potential traffic problems in the Piers area generated by projected development; minimized degradation of the natural environment; preservation of existing neighborhood and community cohesion; and provision of efficient and productive transit service. FTA approves the report and initiation of preliminary engineering for the locally preferred alternative on June 2, 1993.

### **1994-1995**

The Final Environmental Impact Statement/Final Environmental Impact Report (FEIS/FEIR) for the Transitway Project is issued on December 22, 1993. The FEIS/FEIR responds to comments received on the DEIS/SDEIR, and selects trackless trolleys as the vehicle technology for Transitway operation. A public meeting on the FEIS/FEIR is held on January 12, 1994. The Secretary of the Massachusetts EOE issues a Certificate on February 16, 1994 finding that the FEIS/FEIR adequately and properly complied with the MEPA, completing the Federal environmental review process.

As directed by the Secretary of EOE in the FEIS/FEIR Certificate dated February 16, 1994, a Draft Section 61 Finding is prepared and circulated for public review, demonstrating that the MBTA has taken all feasible measures to avoid or minimize potential adverse impacts of the project. The Draft Section 61 Finding also addresses two issues that were left unresolved in the FEIS/FEIR: 1) whether to take or underpin the New England Seafood Center, and 2) the location of the Transitway maintenance facility. Comments received from reviewers are transmitted from the Secretary of EOE to the MBTA in a letter dated November 30, 1994. A Final Section 61 Finding is prepared, responding to all comments and recommendations received from the Secretary of EOE. The filing of this finding on April 18, 1995 completes the state environmental review process.

### **1998-1999**

The Massachusetts Port Authority (Massport) decides to cancel its proposed \$300 million people mover around the airport terminals in favor of bus service from



#### **4. PLANNING, DESIGN AND IMPLEMENTATION**

South Station to the airport terminals, via the Transitway tunnel and the recently completed Ted Williams Tunnel (TWT). Massport agrees to enter into an agreement with the MBTA to procure additional vehicles for this service, and also to subsidize the additional operating costs. The first phase is to be a Massport-sponsored bus operating on surface streets from South Station to the TWT.

In February 1998, the MBTA issues an Environmental Assessment/Notice of Project Change for Transitway Initial Vehicle Technology and Connector Road, describing the environmental impacts and mitigation for two project changes: The vehicle technology for the first phase of the Transitway (South Station to World Trade Center) is proposed to be a dual mode vehicle, rather than trackless trolley. Construction of a "Connector Road" (later called Silver Line Way) from the Transitway portal at D Street to the Massport Haul Road is proposed.

The MBTA decides to combine the South Boston Piers Transitway with the Washington Street Replacement service, both to be called the "Silver Line." In response to an August 1998 EOEА certificate, the MBTA issues a combined Notice of Project Change in May 1999. The document addresses the combined Silver Line and responds to comments on the February 1998 Transitway EA/NPC. On August 9, 1999, the Secretary of EOEА issues a certificate requiring the MBTA to prepare annual informational updates on the combined Silver Line projects.

#### **2000-2001**

In November 2000, Massport begins a shuttle bus, "Logan Dart", from South Station to the Logan Airport terminals via the Ted Williams Tunnel. The fare is \$5 each way (plus fare to get to South Station), with service from 8 am to 6 pm. Ridership is low, and Massport cancels the service in November 2001 following the decline in airport passengers in the wake of 9/11.

In April 2001, the MBTA issues an Environmental Assessment/Notice of Project EA/NPC describing the environmental impacts of siting the maintenance facility at a new location on Southampton Street. The FEIS/FEIR had described the impacts of a facility in the South Boston Waterfront area. A certificate on the EA/NPC is issued on May 25, 2001 in which the Secretary determines that no further environmental review of the facility at the Southampton Street location is required.

The first Annual Update (as required by EOEА) is filed in April 2001. It describes progress made on new ridership estimates for the full Silver Line; the manufacturer's design and performance standard of the dual mode vehicle to be used in the Phase II Silver Line; the consistency of the vehicle types and performance with EPA policies and guidelines; and operations plans of the Silver Line, including the coordination with service to Logan Airport.





## **4. PLANNING, DESIGN AND IMPLEMENTATION**

### **2002**

The MBTA expands the process to plan the surface routes in South Boston by forming, in December 2001, the South Boston Waterfront Transit Advisory Committee (SBWTAC), with members representing elected officials, public agencies, businesses, developers, environmental and public health advocates, and neighborhood organizations. The MBTA also holds briefings with key South Boston political, community, and business leaders, and holds public meetings in residential South Boston as well as in the Waterfront.

A second Annual Update is filed in October 2002, summarizing progress on the proposed Phase III of the Silver Line. It describes the new South Boston Waterfront Transit Advisory Committee, created to provide community input on Silver Line operating plans.

### **2004-2005**

Trunk service starts on December 17, 2004. SL2 and SL3 service begins on December 30, 2004, along with Sunday service to the airport. Full SL1 service begins on June 1, 2005.



**Figure 4-1: Opening Day ceremony at Courthouse Station (MBTA)**



## **4. PLANNING, DESIGN AND IMPLEMENTATION**

### **4.2 FUTURE BRT PROJECTS**

#### **Silver Line Phase III**

The MBTA is seeking a Federal grant for Phase III of the Silver Line which is proposed to link the two existing portions in a tunnel. In January 2002, the MBTA filed a preliminary New Starts application with the Federal Transit Administration seeking New Starts funds for 60% of the cost of Silver Line Phase III. In July 2002, the FTA issued its first review of the Silver Line New Starts application and listed the project as Recommended. As part of this first rating, the MBTA was also given permission to begin Preliminary Engineering for the project. On August 17, 2005, the General Manager requested FTA to take MBTA Silver Line III Project out of Preliminary Engineering (PE) from the Federal New Starts Program for the FY2007. Subsequently, on September 2, 2005, a letter from the Assistant General Manager from Design and Construction directed the Joint Venture to stop all tasks associated with the design and engineering to 15% and 30% levels for the tunnel and system wide elements of Silver Line III project, but to continue work on the Environmental and Public Involvement Tasks. This allowed the necessary time for the MBTA to gain public support on a preferred alignment. On August 16, 2006, the General Manager requested FTA approval to return to PE while submitting the FY2008 New Starts Application. On December 12, 2006, FTA granted the MBTA approval to return to PE and the FTA again rated the Silver Line Phase III as Recommended.

In May 2005, the MBTA released an environmental document that assessed the environmental impacts of four possible alignments: three alignments with a portal on Washington Street and one alignment with a portal on Columbus Avenue. Two aspects of these proposals were contentious: the use of a small urban neighborhood park for up to 24 months, which would require approval by two thirds of the members of both houses of the state legislature; and the proximity of the Washington Street portal to a hospital, hotel and Chinatown neighborhoods. Given the lack of consensus, the MBTA put the project on hold for further study.

On March 8, 2006, the MBTA announced a new portal location for Silver Line Phase III, on Tremont Street, just south of the Church of All Nations. The route would use contraflow lanes on both Herald Street and Marginal Road to make the connection to Washington Street. The MBTA plans to submit a joint state and federal environmental document in the first quarter of 2008 (see Figure 4-2).

The MBTA is also considering the use of BRT for the Urban Ring, a proposed circumferential transit route.



## 4. PLANNING, DESIGN AND IMPLEMENTATION

Figure 4-2: Silver Line Phase III Alignment



Map courtesy of MBTA



## **5. EVALUATION OF SYSTEM PERFORMANCE**

### **5.0 EVALUATION OF SYSTEM PERFORMANCE**

The Silver Line Waterfront introduced a number of features aimed at improving bus service in Boston. Our evaluation of system performance is presented in this section and covers a number of the attributes that have been identified in FTA's *Characteristics of Bus Rapid Transit for Decision Making*. These include:

- Travel Time
- Reliability
- Identity and Image
- Safety and Security
- Capacity
- Each of these attributes is discussed below.

#### **5.1 TRAVEL TIME**

The Automatic Vehicle Location data gathered from the Silver Line Waterfront routes relies on dead reckoning in addition to GPS transmission because the latter is often impossible inside the Transitway tunnel, the Ted Williams Tunnel, and sometimes under airport terminal structures. Dead reckoning helps to prevent problems with capturing time points at airport terminals and staying on-course in the tunnels, but is not 100% accurate. For example, the system will sometimes record an arrival and departure simultaneously at a layover point, rather than an arrival at the beginning of the layover and a departure at the end; this can lead to the layover time being included as part of the running time in the preceding or following trip. The errors due to these data problems are somewhat reduced by reporting hourly average travel time. The greatest variation in data availability is by day. Some days no trips, or very few, are captured by the system and on other days as many as 75% of all trips are recorded.

#### **Running Time**

##### *SL1 to Logan Airport*

Because the SL1 runs in a loop around the airport terminals to simultaneously drop off passengers going to the airport and pick up passengers coming from it, there is no clear line between "inbound" and "outbound" from the customer's perspective. For scheduling purposes, "inbound" (to downtown Boston) runs from Logan Airport Terminal A, making stops at all the other terminals, and then operating non-stop from Terminal E to Silver Line Way, via the Ted Williams Tunnel. From there it travels the trunk route to South Station. SL1 "outbound" (away from downtown Boston) is just the route from South Station to Terminal A; the airport loop is considered inbound only. The round-trip distance is 8.9 miles. The scheduled



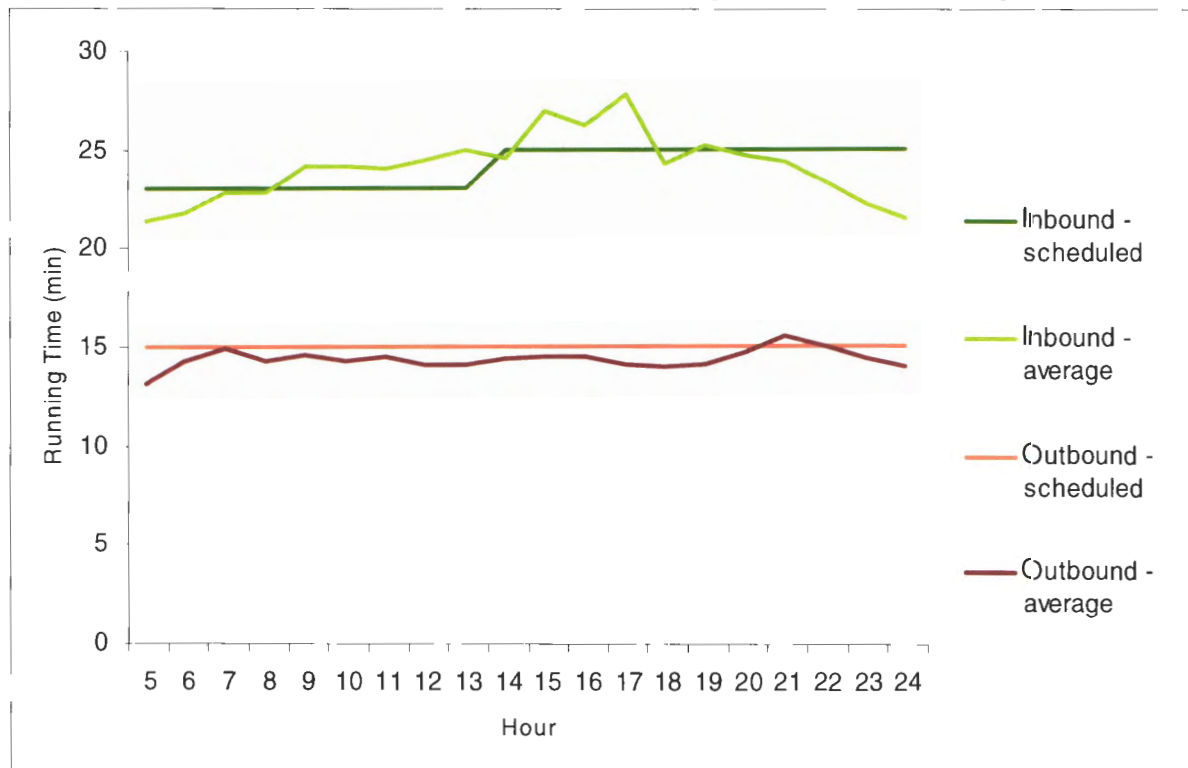


## 5. EVALUATION OF SYSTEM PERFORMANCE

inbound time is 23-25 minutes; outbound is 15 minutes. The schedule assumes an average operating speed of 14 mph.

Figure 5-1 shows scheduled and actual average running time for SL1, based on AVL data from February 2007. The outbound actual average running time is below the scheduled time almost every hour of the day. The longer inbound trips, which include all of the airport activity, have average running times at or slightly above their scheduled running time every hour of the day except for late nights and early mornings. During the 3 pm to 6 pm peak, outbound trips average 1 to 3 minutes longer than scheduled.

**Figure 5-1: Average and scheduled running time, SL1 to Airport**



### *SL2 to Boston Marine Industrial Park (BMIP)*

Route SL2 outbound uses the Transitway to Silver Line Way, and then travels on Northern Avenue to Dry Dock Avenue. The morning outbound and afternoon inbound trips loop around Boston Marine Industrial Park. This minimizes walking time since by far the predominant passenger flow is from downtown transit connections to the Seaport in the morning (outbound) and from the Seaport back to downtown in the evening (inbound). Peak-direction trips are thus both farther and have more passenger activity. Outbound morning trips are scheduled at 14 minutes

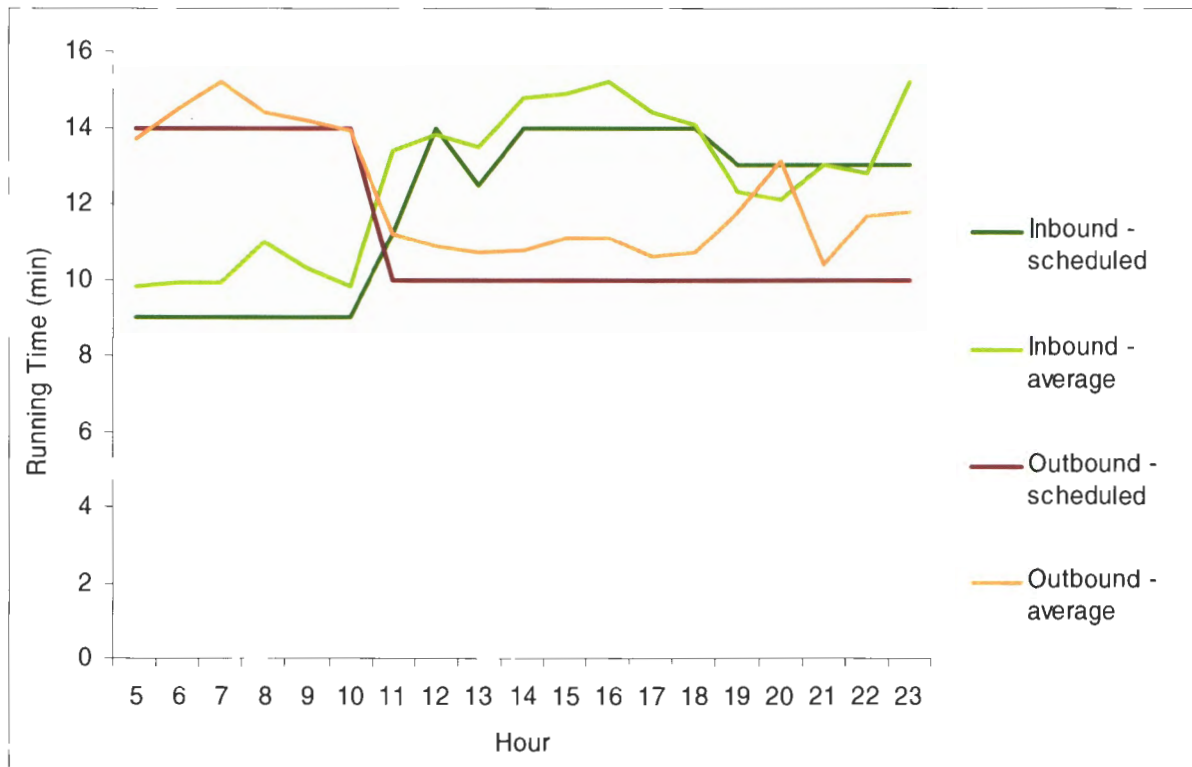


## 5. EVALUATION OF SYSTEM PERFORMANCE

in the morning (when they make the loop) and 10 minutes in the afternoon (when they do not). As shown in Figure 5-2, the actual travel times are generally only slightly above the scheduled time.

Before the Silver Line opened, MBTA local bus Route 3 took about the same time to make the trip from South Station to BMIP despite lower ridership numbers. According to the Summer 2004 schedule, Route 3's running time from South Station to BMIP was 11 minutes in the morning peak outbound, although this includes only the time from leaving to South Station to arriving at the park, not looping it. Ride checks by CTPS in Fall 2004 show that all morning peak trips checked completed their total run in the 24 minutes allotted or less. The modest impact on running time is in part due to differences in ridership. In the AM peak, Route 3 averaged just 16 riders per outbound trip (including some riding outside the segment under discussion) compared to 57 for the SL2. (Please see later discussion on the impact of ridership on running time.) Another contributing factor is that the Transitway tunnel has a maximum speed of 25 mph in tunnel, with buses traveling frequently at lower speeds. The scheduled running time between South Station and World Trade Center is four minutes, and includes the dwell time both at World Trade Center Station and Courthouse Station, leaving little room for improvement.

**Figure 5-2: Average and scheduled running time, SL2 to BMIP**





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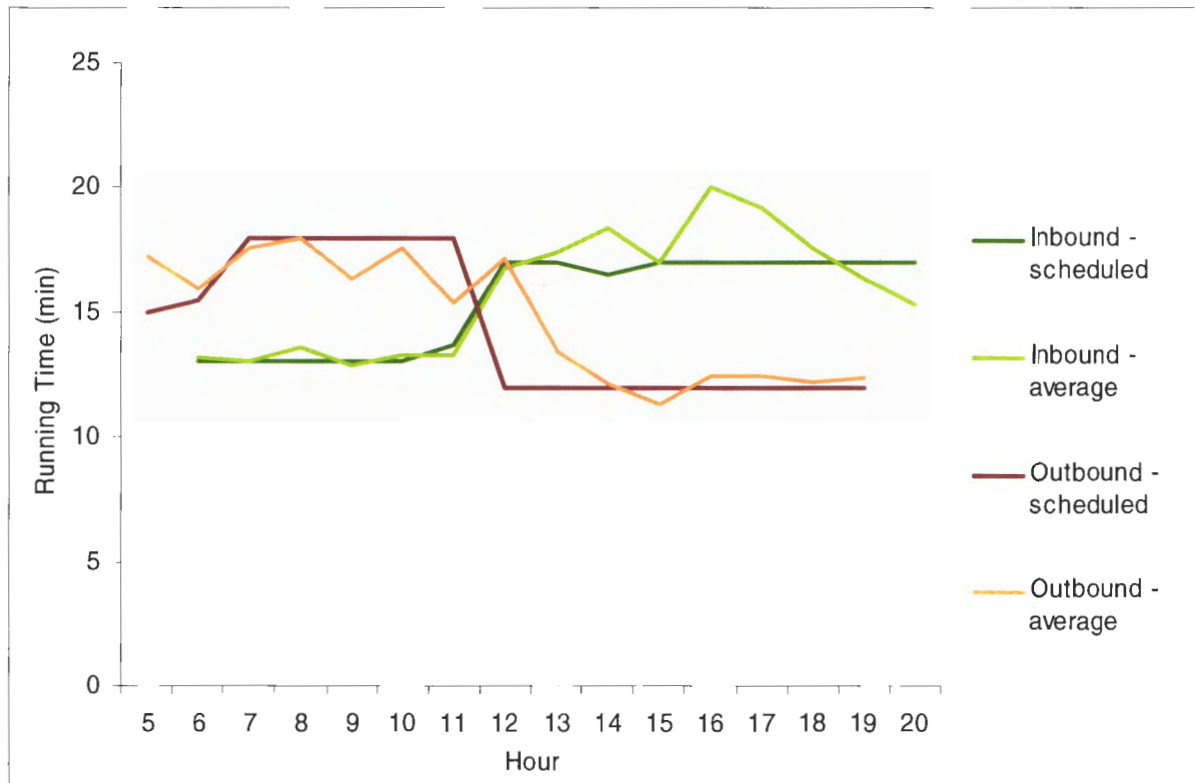
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## 5. EVALUATION OF SYSTEM PERFORMANCE

### *SL3 to City Point*

Route SL3 runs on Northern Avenue to Dry Dock Avenue, and like SL2 loops around BMIP only in the peak time and direction (morning outbound, afternoon inbound). Unlike SL2, SL3 continues to Summer Street and City Point, at the edge of residential South Boston. Like the SL2 it has highest ridership outbound in the morning and inbound in the afternoon. As shown in Figure 5-3, actual outbound average travel times are consistently several minutes less than the scheduled running time. Inbound travel times are similar to outbound (11 to 12 minutes if not looping, 16 to 18 minutes if looping), but are scheduled much more tightly: during most hours of the day, the scheduled time for SL3 is equal to or less than the actual average. According to the Summer 2004 schedule, Route 3's running time from South Station to City Point was 14 minutes in the morning peak outbound, about the same as SL3, although the number of riders per trip on the local bus route was much lower than on the Silver Line route.

**Figure 5-3: Average and scheduled running time, SL3 to City Point**



### *Other Routes Affected*

As many passengers shifted from other routes to Silver Line Waterfront it allowed those routes to be altered or simplified (see Project Summary). The change to Route 7 allowed it to provide faster service between the South Boston Waterfront and downtown. Its round trip time was reduced by 4 to 8 minutes. The running time savings were used to provide more frequent peak-period service.



## 5. EVALUATION OF SYSTEM PERFORMANCE

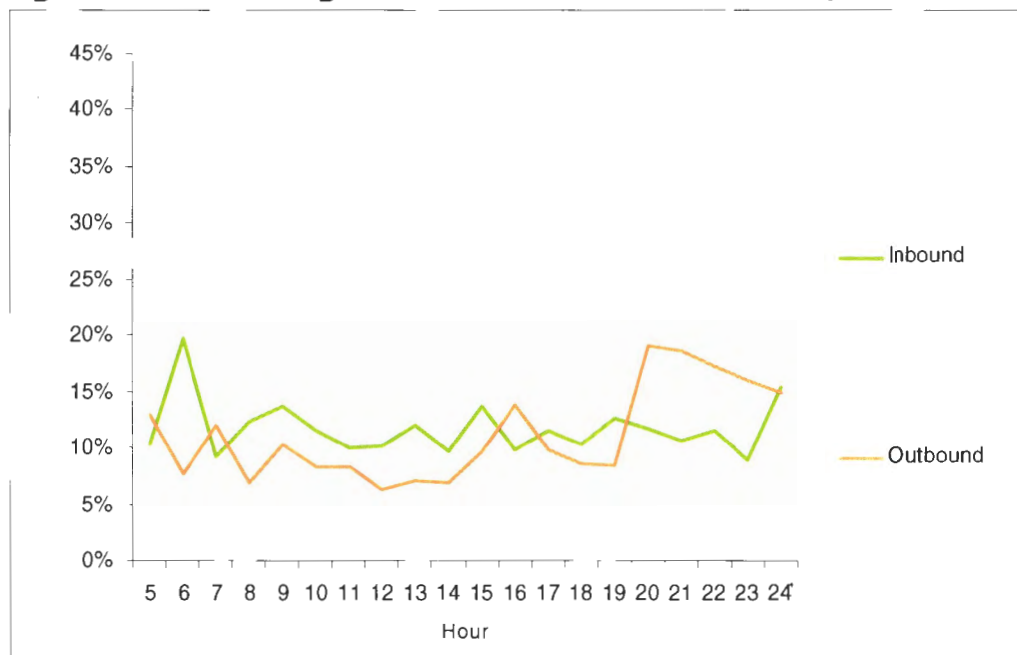
### Dwell Time

The three stations in the Transitway tunnel (South Station, Courthouse, and World Trade Center) have barrier fare collection. Fare is paid at gates, before passengers arrive at the platform, enabling all three doors to be used for boarding. At all other stops, fare is paid on entry, and only the front door is used for boarding. Since late 2006, contactless "smart" cards ("Charlie Cards") have been accepted on Silver Line buses, thus reducing boarding time on surface stops.

### 5.2 RELIABILITY

The AVL data are useful to measure reliability because they provide running time for many hundreds of trips. One measure of reliability is average running time divided by its standard deviation (this measure is called the "coefficient of variation" or CV). In figures 5-4 to 5-6 we show running time coefficient of variation by hour of the day. For route SL1, the CV is impressively low: around 10% most hours of the day and never more than 20%. Routes SL2 and SL3 have higher variation, at least at some periods of the day. There are several possible explanations for the differences between the three routes. First, they generally have a shorter mean running time, so a smaller deviation translates into a higher percent deviation. Second, there are fewer trips, so a single unusual trip (or bad data, in some cases) may bias the results. Thirdly, the MBTA has inspectors at South Station scheduling departures for route SL1 (only) every 10 minutes, regardless of the scheduled trip departure time. This policy reduces bunching and thereby reduces the variation of total running time, since frequent bunching leads to greater variability of travel time.

**Figure 5-4: Running Time Coefficient of Variation, SL1**

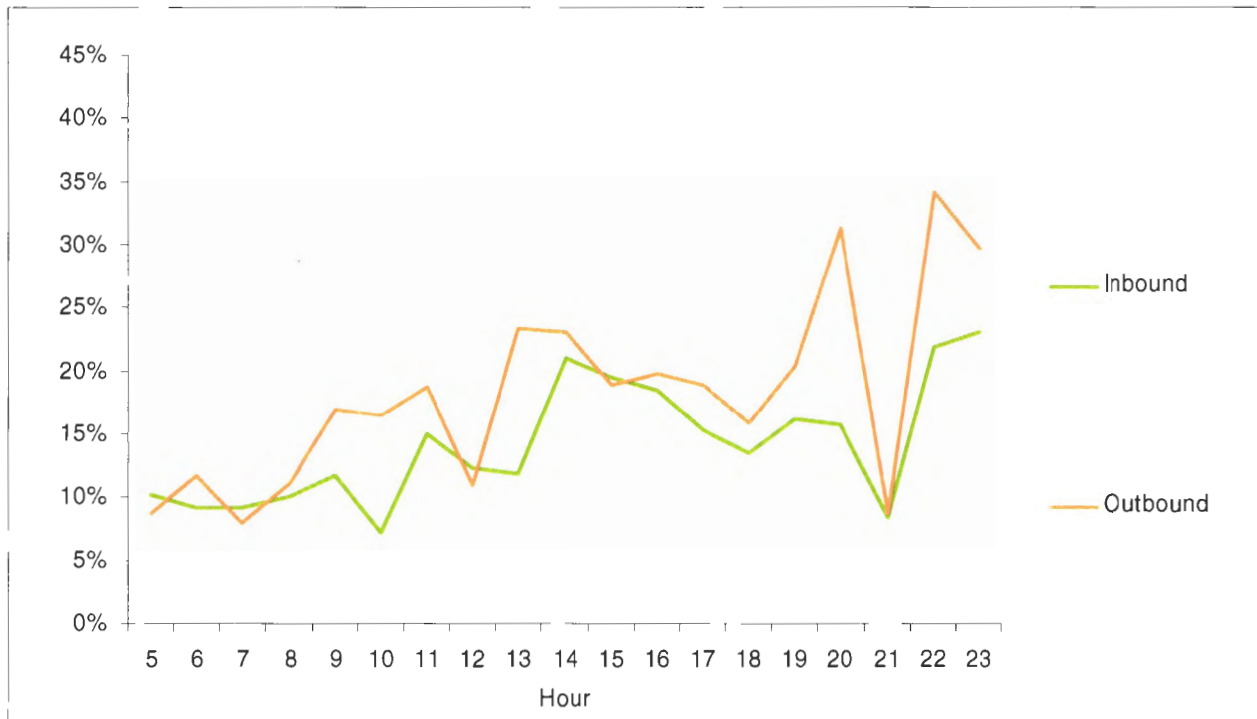




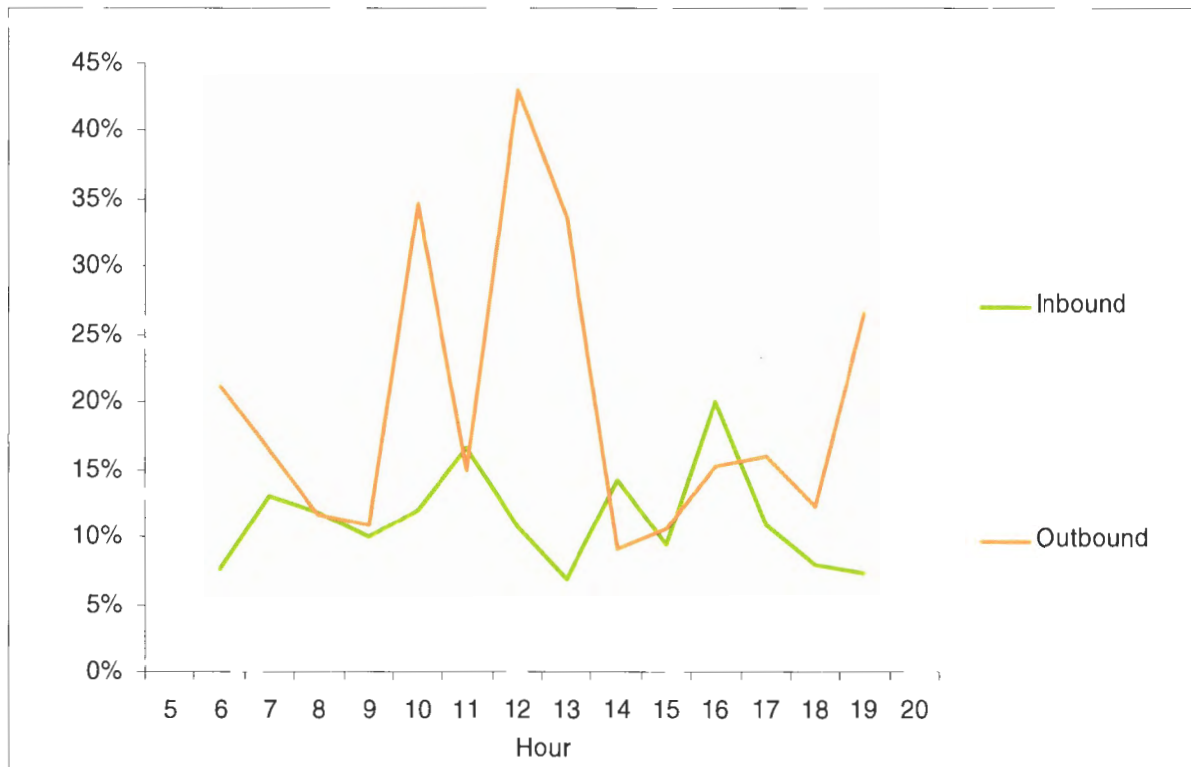


## 5. EVALUATION OF SYSTEM PERFORMANCE

**Figure 5-5: Running Time Coefficient of Variation, SL2**



**Figure 5-6: Running Time Coefficient of Variation, SL3**





## 5. EVALUATION OF SYSTEM PERFORMANCE

### Riders Surveys

Another source of data about travel time and reliability is surveys of transit riders; we have two such surveys available.

The Seaport TMA 2005 surveyed several hundred employees who work in the South Boston Waterfront and who ride the Silver Line Waterfront at least occasionally. They were asked to rate their satisfaction with several aspects of service, including frequency, reliability, and travel time (see Table 5-2). In each case 80 to 90% of respondents were satisfied or very satisfied, with travel times rated the highest.

**Table 5-1: Silver Line Service Quality Assessment, Seaport-Area Workers**

|                   | Frequency of service | Reliability (on-time performance) | Travel Time |
|-------------------|----------------------|-----------------------------------|-------------|
| Very dissatisfied | 3%                   | 6%                                | 3%          |
| Dissatisfied      | 13%                  | 11%                               | 6%          |
| Satisfied         | 48%                  | 49%                               | 36%         |
| Very Satisfied    | 36%                  | 34%                               | 55%         |
| TOTAL             | 100%                 | 100%                              | 100%        |

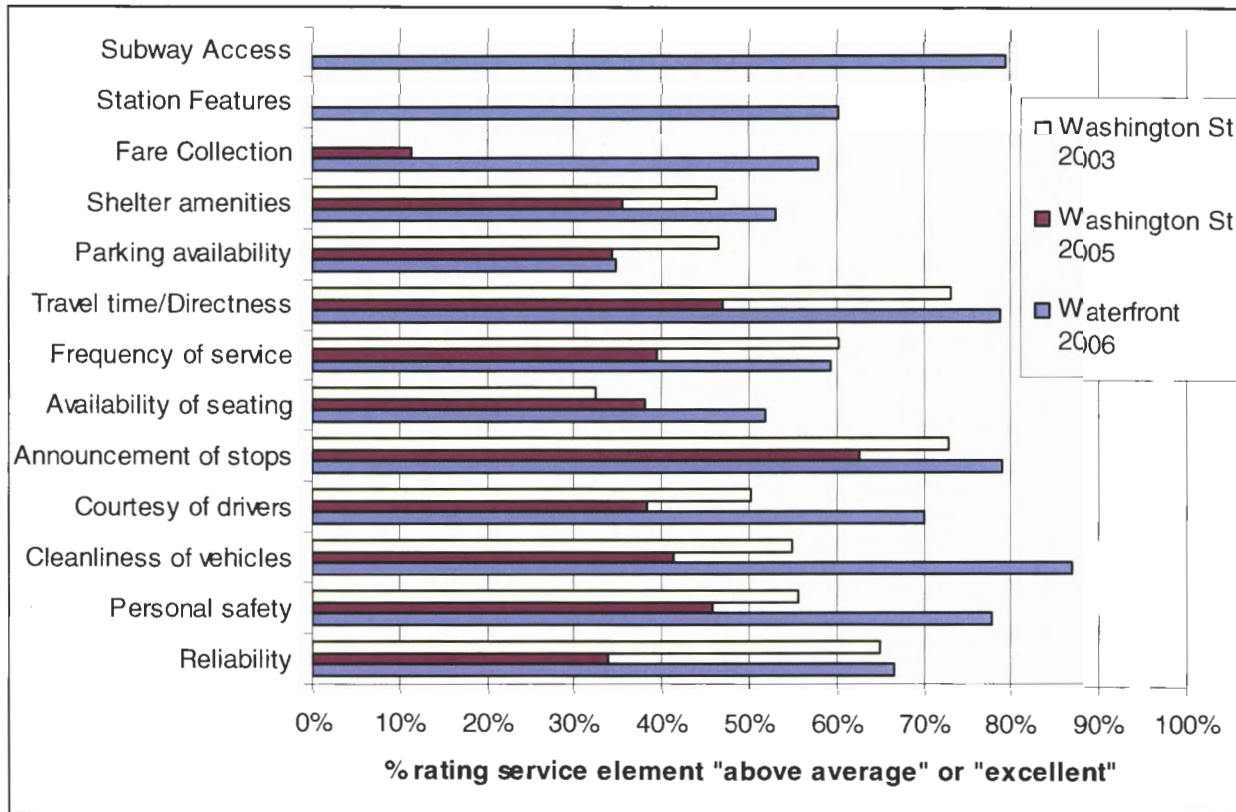
Also, the Central Transportation Planning Staff has conducted surveys of Silver Line passengers for the MBTA. The results of the questions about elements of service quality are shown in Figure 5-7, including a 2006 survey of Waterfront service and, for comparison, 2005 and 2003 surveys of Silver Line Washington Street. The Table shows the percent of respondents rating each service quality element as "above average" or "excellent." The survey also asked respondents if each element was among the three most important factors, in the respondent's opinion. For each of the three surveys, "reliability" was mentioned by far the most frequently as one of the top three and "frequency of service" was the second most common. Travel time was generally the third most common. For these three attributes, the Waterfront service scores are somewhat but not greatly higher than the Washington Street 2003 survey results. The 2005 Washington Street survey showed a significant drop in ratings for almost every service attribute, including these three most important. This change can be explained by the new fareboxes that were pilot-tested on the Washington Street service beginning in early 2005 that resulted in a significant increase in boarding delays and travel times (see Boston Silver Line Washington Street BRT Demonstration Project Evaluation, FTA-VA-26-7222-2005.2).<sup>6</sup>

<sup>6</sup> The sole improvement was the rating for "availability of seats," which is explained by the addition of articulated buses on the Washington Street service between the 2003 and 2005 surveys.



## 5. EVALUATION OF SYSTEM PERFORMANCE

**Figure 5-7: Service Quality Ratings, Silver Line Waterfront and Washington Street Passenger Surveys**



Although a similar study on the MBTA’s area bus routes was not conducted before Waterfront service began, it is worth noting that the routes that previously served the area were among the higher generators of complaints. This is especially true of route 7, which generated many crowding and on-time performance complaints, but is also true of the 3, 6 and 11 (although not the 4.) Complaints for area service overall decreased with the opening of the Silver Line Waterfront, due to both the shift to the Waterfront and the changes that the existence of the Waterfront service facilitated in those routes (see “Project Summary.”)

### 5.3 IDENTITY AND IMAGE

The idea of the Silver Line and BRT in general, is to make a rubber-tired service that is perceived in the same way as rail rapid transit service. All of the MBTA core system rail services have a color-coded name. Thus the concept was to add an additional color-coded branch to the system, a “fifth rapid transit line.” By being part of the “rapid transit” system, the Silver Line, alone among the bus routes, is included in the system spider map displayed at all stations and in the Rapid Transit route schedule pamphlet. Transfer opportunities to the Silver Line are announced on other rapid transit services. Anecdotally, the MBTA’s efforts to present it as a rapid transit service appear to have been successful. Regular customers have even been heard to refer to the vehicles as “trains.”



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The MBTA conducted a marketing campaign for the opening of the Silver Line on Washington Street in 2002, including a Silver Line logo used on signs, and web and print materials. This logo was not created by the marketing department. The title of the Silver Line public information campaign, "Dig for Silver," emphasized the Transitway tunnel, a key component of Phase II. Between 2002 and 2006, the MBTA had a Silver Line website with a separate URL from the regular MBTA website that contained information on all three phases of service.

On December 17, 2004, the MBTA held an opening day party for Silver Line Waterfront, including music, food, and free rides. The opening of the second phase of the Silver Line in 2004 created the possibility of confusion with two unconnected services with the same name. Therefore the decision was taken to call the first phase "Silver Line Washington Street" and the second phase "Silver Line Waterfront." The MBTA is planning to link the two services in a tunnel, but the current projected opening date is 2016.



Figure 5-8: Passenger information at Logan Airport terminal (P. Schimek)





## 5. EVALUATION OF SYSTEM PERFORMANCE

### 5.4 SAFETY AND SECURITY

The study team considered the effect of new, high quality, well-maintained Silver Line stations has improved on the actual or perceived safety and security for transit users while waiting and riding the service. We looked at crime data, survey responses, and anecdotal evidence to determine if there has been an impact on community safety, or perceptions of safety.

Interviews with the MBTA indicate that the neighborhood in which Silver Line Waterfront operates is considered one of the safer areas in the city. Silver Line Waterfront has had few criminal incidents, in part due to the clientele it serves.

The Seaport TMA's 2005 survey of Seaport-area employees asked them to rate personal safety on the Silver Line Waterfront. As shown in Table 5-3, 92% of respondents were satisfied or very satisfied with personal safety. The 2006 CTPS passenger survey found that 78% of respondents rated personal safety as above average or excellent.

As mentioned in Section 3, the Transitway tunnel includes advanced security systems to prevent intruders and deter terrorists. The MBTA conducts safety drills in the tunnel that include police and fire departments. However there have been no incidents to date in the tunnel.

**Table 5-2: Silver Line Personal Safety Assessment**

|                               | Above Average or Excellent | Satisfied or Very Satisfied |
|-------------------------------|----------------------------|-----------------------------|
| <b>All riders</b>             | 78%                        | -                           |
| <b>Seaport-area employees</b> | -                          | 92%                         |

Sources: All riders: CTPS passenger survey 2006. South Boston Waterfront employees: Seaport TMA survey 2005.

The evaluation team investigated crime in the corridor using incident summaries for Silver Line Waterfront from December 2004 to October 2006 obtained from the MBTA Transit Police. The MBTA Transit Police are jurisdictionally responsible for crimes at stations and on vehicles operated by MBTA. The crimes they track are divided into Part I and Part II crimes. Part I crimes include criminal homicide, rape, aggravated assault, robbery, larceny, motor vehicle theft, burglary, and arson. As of October 2006, no Part I crimes have occurred on Silver Line Waterfront. In the same time period, seven Part II crimes occurred on Silver Line Waterfront, including trespassing, assault and battery on a police officer, larceny under \$250, assault on an MBTA employee, disorderly person, destruction of property, and fare evasion.



## 5. EVALUATION OF SYSTEM PERFORMANCE

In order to compare these crime statistics to system wide data, MBTA provided system wide crime statistics for 2005 and January to October 2006. In 2005, there was 3088 crimes system wide. Of these, 1003 (32%) were Part I crimes. From January 1, 2006 to October 31, 2006, of the 2976 crimes occurring system wide, 27% were Part I crimes (793). With a system wide ridership of approximately 395 million unlinked trips in 2005, this equates to 7.8 total crimes per million trips. By comparison, Silver Line Waterfront's ridership in 2005 was approximately 2.5 million trips. With only one crime occurring in 2005, there were only 0.4 total crimes per million trips.

### *Traffic Safety*

Between December 1, 2004 and September 20, 2006, 44 bus accidents occurred on Silver Line Waterfront routes. Of these 44 accidents, only four resulted in injury. Comparable accident data for the system as a whole were available only for January to August 2006. The number of accidents per 100,000 vehicle miles for that period for Silver Line Waterfront and the system is shown in Table 5-4.

**Table 5-3: Silver Line Waterfront Traffic Accidents and Injuries Compared to MBTA System, January 2006 to August 2006**

|                            | Accidents | Injuries | Accidents / 100,000 veh mi | Injuries / 100,000 veh mi |
|----------------------------|-----------|----------|----------------------------|---------------------------|
| Silver Line Waterfront     | 23        | 3        | 5.86                       | 0.76                      |
| MBTA System wide           | 1382      | 225      | 9.69                       | 1.58                      |
| Silver Line as % of System |           |          | -40%                       | -52%                      |

The accident rate on Silver Line Waterfront (5.86 per 100,000 vehicle miles) is 40% lower than the average rate system wide on MBTA buses (9.69 per 100,000 vehicle miles). The injury rate on Silver Line Waterfront (0.76 per 100,000 vehicle miles) is lower still, less than half the rate system wide on MBTA (1.58 per 100,000 vehicle miles).

### 5.5 CAPACITY

In theory, capacity is constrained by the number of people that can fit on a bus, the number of buses that can fit on a platform or stop, and the number of buses that can share the Transitway without slowing each other down. The Silver Line Waterfront is not near any of these limits. Because there are no residences served by the Silver Line, ridership is very directional: most riders are traveling outbound to the Seaport in the morning and inbound to downtown Boston in the evening (this is less true for airport service). As shown in Figure 5-5, SL2 averaged 40 to 50 riders per trip in the peak hour and peak direction. At all other times, the average was fewer than 10 riders per trip. Even at the few peak hours of the day, the number of boardings per trip (which is generally less than the maximum load) is



## 5. EVALUATION OF SYSTEM PERFORMANCE

well below the legal maximum of 140% of the seated capacity (which means 53 people for airport trips and 65 for all other), let alone the manufacturer's stated capacity of 96 passengers. This allows for growth as the area continues to develop as both a workplace and a residential neighborhood.

**Table 5-4: Total and average riders per trip, peak hours and direction vs. all other times, SL2, Spring 2005**

|   | Total Daily Riders |         | Riders per Trip |         |
|---|--------------------|---------|-----------------|---------|
|   | Outbound           | Inbound | Outbound        | Inbound |
| Peak hour, peak direction*              | 1,152              | 817     | 52              | 43      |
| All other times                         | 512                | 416     | 9               | 8       |
| Total                                   | 1,664              | 1,233   | 21              | 17      |
| % of all trips in peak hour & direction | 69%                | 66%     |                 |         |

\*6 am to 9:30 am outbound and 4 pm to 6:30 pm inbound. Source: Authors' calculations from CTPS ride checks.



## 6. SYSTEM BENEFITS

### 6.0 SYSTEM BENEFITS

#### 6.1 RIDERSHIP

The Silver Line Waterfront buses are not equipped with automatic passenger counters. Therefore, the main ridership data consists of manual counts conducted periodically by the Central Transportation Planning Staff (CTPS) under contract to the MBTA. Ridership was counted in Spring 2006; the results are shown in Table 6-1. However, some of the 5,000 riders using the airport service are taking trips within the South Boston Waterfront and merely happen to be boarding an airport-bound route (which operates more frequently than the other two branches). The number of those not going to the airport can be estimated from boardings and alightings per stop reported from the same series of counts.

**Table 6-1: Silver Line Waterfront weekday boarding counts Spring 2006**

|       |   |        |
|-------|---|--------|
| SL1   | Logan Airport - South Station                 | 5,023  |
| SL2   | Boston Marine Industrial Park - South Station | 2,863  |
| SL3   | City Point - South Station                    | 1,923  |
| SLWat | Silver Line Way - South Station               | 1,197  |
|       | All branches                                  | 11,006 |

Those going to Logan Airport and those going to the South Boston Waterfront are fundamentally two different groups of riders. The Seaport-Area riders tend to be employees making work trips daily, whereas Logan-bound riders tend to be occasional air passengers travelers. One statistic, monthly pass use, tells the story. More than three-quarters (77%) of Seaport riders used a monthly pass, but only 24% of Logan riders did so, based on the 2006 Passenger Survey conducted by CTPS.

#### Seaport-Area Riders

Table 6-2 summarizes the number of transit riders going to the South Boston Waterfront before and after the Silver Line service began. The shuttle bus service estimate is from 2001 and may be too high because jobs growth peaked in that year; it may be too low because several new buildings opened in the South Boston Waterfront between 2001 and the start of Silver Line service at the end of 2004. These figures suggest that about half the South Boston Waterfront riders were previously taking MBTA local bus or private shuttle. In other words, transit ridership to the South Boston Waterfront has about doubled (98% increase) from that base, if the "before" estimates are correct.





## 6. SYSTEM BENEFITS

**Table 6-2: South Boston Waterfront transit ridership before and after Silver Line opening**

| Transit Service                                    | Before Silver Line | After Silver Line |
|--|--------------------|-------------------|
| Private shuttles to South Station                  | 2,950              | 0                 |
| MBTA local bus routes 3, 4, and 6                  | 806                | 374               |
| SL2, SL3, and SL trunk service                     | -                  | 5,997             |
| SL 1 riders getting off in South Boston Waterfront |                    | 1,063             |
| <b>TOTAL RIDERSHIP</b>                             | <b>3,756</b>       | <b>7,434</b>      |

Note: local bus counts are from Fall 2004 and Fall 2005. Silver Line counts are from Spring 2006. The shuttle bus ridership estimate is from 2001.

Table 6-3 shows the previous mode used before the Silver Line opening, from the CTPS 2006 Passenger Survey. It shows that about 25% of those going to the South Boston Waterfront were previously using a shuttle bus and 10% were previously using an MBTA local bus. The single largest group (28%) previously walked, and 25% did not previously make the trip. Only 8% previously made the trip by automobile.

**Table 6-3: Distribution of Silver Line Waterfront Riders by Previous Mode Used and Destination, CTPS 2006 Passenger Survey**

|                | To or From South Boston Waterfront | To or From Logan Airport |
|----------------|------------------------------------|--------------------------|
| Automobile     | 8%                                 | 22%                      |
| Walk           | 28%                                | n/a                      |
| Shuttle Bus    | 25%                                | n/a                      |
| MBTA Subway    | n/a                                | 48%                      |
| MBTA Bus       | 10%                                | n/a                      |
| Did Not Travel | 25%                                | 18%                      |
| Other          | 4%                                 | 12%                      |
| <b>Total</b>   | <b>100%</b>                        | <b>100%</b>              |



## 6. SYSTEM BENEFITS

### Airport Riders

The other major destination of Silver Line Waterfront passengers is Logan Airport. MassPort collects monthly counts of inbound passenger loads departing Terminal E for Boston. These data are graphed in Figure 6-1. It can be assumed that total ridership, including both inbound and outbound trips, is roughly twice these counts. The data show one-way ridership averaging less than 1,000 per day at the start of service in June, 2005, rising to roughly 1,500 per day by early 2006, when the MBTA added to evening and weekend service to keep pace with demand. The fourth quarter of 2006 showed average daily ridership generally above 2,000 per day. These estimates are in line with the Spring 2006 CTPS count, which found more than 3,566 riders boarding or alighting at airport stops (5,023 SL1 boardings less 1,063 not going to or from the airport), corresponding to about 2,035 inbound trips. Although the graph shows spikes in November, it does not capture the spike in demand that surrounds the Thanksgiving holiday. In the Thanksgiving season the MBTA increases service up to a 6-minute headway to meet the increased demand for airport service. Their internal estimates show 7,000 airport travelers each day on the two days before Thanksgiving, a 144% increase over typical daily airport ridership.

**Figure 6-1: Average Daily Inbound Ridership from Logan Airport**



Source: Massachusetts Port Authority, Silver Line Waterfront Terminal E Counts.



## 6. SYSTEM BENEFITS

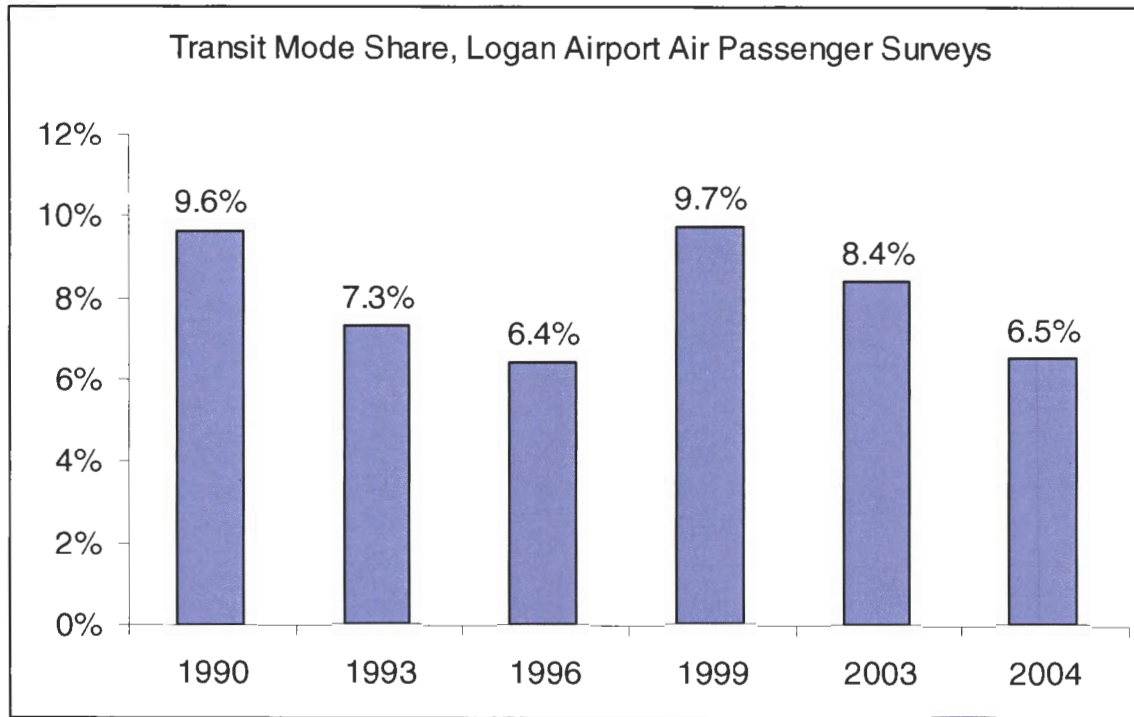
Table 6-3 shows the previous mode of Airport-bound Silver Line riders, based on the 2006 CTPS passenger survey. Nearly half previously used the MBTA Blue Line subway. About 22% previously used an automobile—either getting dropped off or parking at or near the airport. The remaining 12% took another mode. Most of these were taxi riders (“taxi” was not an option printed on the survey). These results suggest that about half of the Airport-bound Silver Line ridership consists of new transit trips. Because about one-third (22% auto plus 12% “other”) used a private mode (car or taxi), there may have been a net gain in the transit share of Logan air passenger trips. The Massachusetts Port Authority periodically conducts Logan Air Passenger Surveys to determine (among other things) the ground access mode used by air travelers. The last such survey was conducted in 2004; the next is planned for Spring 2007. Results from past surveys since 1990 are shown in Figure 6-2. The transit mode share varied from 6.4% to 9.7% between the 1990 and 2004 surveys, but there was no trend up or down. This variation may be the result of random variation within a small sample. The next survey may not therefore show a statistically significant change in the transit share.

Using the data shown in Figure 6-1, we calculated average daily ridership for all of 2006 of as 1,655 weekdays and 1,803 weekends. This equates to an average of 12,324 one-way trips per week, 24,649 round trips per week, and 1.28 million per year (multiplying by 52). Since 48% of these were previously made by Blue Line subway (according to the 2006 CTPS survey), 52% or about 666,500 are new. This would represent a 24% increase compared to the 2.74 million annual Blue Line trips to Logan Airport estimated for 2004 (Blue Line ridership reported in Massachusetts Port Authority, Logan Airport 2004 Environmental Status and Planning Report, Chapter 5. <http://www.massport.com/about/pdf/edr04/TableOfContents.pdf>).



## 6. SYSTEM BENEFITS

**Figure 6-2: Transit Mode Share, Logan Airport Air Passenger Surveys**



Source: Massachusetts Port Authority, Logan Airport 2004 Environmental Status and Planning Report, Chapter 5.

<http://www.massport.com/about/pdf/edr04/TableOfContents.pdf>

### *Access Mode at South Station*

More than half of Silver Line Waterfront riders arrived at the Silver Line at South Station by MBTA Red Line, as shown in Table 6-4. (The survey did not determine how many transferred to the Red Line from another subway or bus line.) The next largest group, 35% of those going to South Boston and 15% of those going to the Airport, came by Commuter Rail, transferring directly to the Silver Line at South Station. Walk access was the third most common. The remainder came by MBTA bus (mostly Turnpike express bus), privately operated bus, Amtrak, drop off, and other. In total, more than 90% transferred from some other public transit mode.





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**Table 6-4: Access Modes of Silver Line Waterfront Riders Boarding for Outbound Trips, by Destination, CTPS 2006 Passenger Survey**

|                 | To South Boston | To Logan Airport | Total |
|-----------------|-----------------|------------------|-------|
| Walk Only       | 6%              | 17%              | 8%    |
| Red Line Subway | 54%             | 59%              | 55%   |
| T Bus           | 3%              | 1%               | 2%    |
| Private Bus     | 2%              | 1%               | 2%    |
| Commuter Rail   | 35%             | 15%              | 31%   |
| Amtrak          | 0%              | 2%               | 0%    |
| Drop Off        | 0%              | 4%               | 1%    |
| Other           | 0%              | 1%               | 1%    |
| Total           | 100%            | 100%             | 100%  |

### *Demographics of Riders*

Table 6-5 shows the age, gender, and household income of Silver Line Waterfront riders, and, for comparison, of Silver Line Washington Street riders. For Silver Line Waterfront, the percent distribution is shown separately for the South Boston Waterfront and Logan Airport destinations. Most Waterfront riders are of working age (85% are between 25 and 64). There were almost no children (under 18) recorded in the survey. The age distribution of riders was similar for both major destinations, South Boston and Logan Airport. There were somewhat more younger and older riders on the Washington Street service. There were more women than men using the Silver Line, with the highest percentage of women riders on Washington Street. The average household income of Waterfront riders is very high: more than half had household income of \$80,000 or more. This finding holds for both major destinations. By comparison, only 16% of Washington Street corridor riders had income that high, and 31% had annual income less than \$20,000.



## 6. SYSTEM BENEFITS

**Table 6-5: Age, Gender, and Household Income of Silver Line Waterfront and Silver Line Washington Street Passengers, CTPS Passenger Surveys**

|                         | Waterfront           |                       |       | Washington St |
|-------------------------|----------------------|-----------------------|-------|---------------|
|                         | to/from South Boston | to/from Logan Airport | Total |               |
| <b>Age</b>              |                      |                       |       |               |
| 17 or Under             | 0%                   | 0%                    | 0%    | 3%            |
| 18-24                   | 10%                  | 14%                   | 11%   | 11%           |
| 25-34                   | 28%                  | 19%                   | 25%   | 23%           |
| 35-44                   | 27%                  | 27%                   | 27%   | 24%           |
| 45-64                   | 32%                  | 35%                   | 33%   | 30%           |
| 65 or over              | 3%                   | 6%                    | 4%    | 8%            |
| Total                   | 100%                 | 100%                  | 100%  | 100%          |
| <b>Gender</b>           |                      |                       |       |               |
| Male                    | 44%                  | 47%                   | 45%   | 42%           |
| Female                  | 56%                  | 53%                   | 55%   | 58%           |
| Total                   | 100%                 | 100%                  | 100%  | 100%          |
| <b>Household Income</b> |                      |                       |       |               |
| Under \$20,000          | 4%                   | 8%                    | 5%    | 31%           |
| \$20,000-\$29,999       | 3%                   | 3%                    | 3%    | 13%           |
| \$30,000-\$39,999       | 5%                   | 6%                    | 5%    | 15%           |
| \$40,000-\$59,999       | 14%                  | 17%                   | 15%   | 14%           |
| \$60,000-\$79,999       | 16%                  | 13%                   | 15%   | 11%           |
| \$80,000 or more        | 58%                  | 54%                   | 57%   | 16%           |
| Total                   | 100%                 | 100%                  | 100%  | 100%          |

Source: Central Transportation Planning Staff, Silver Line Waterfront 2006 Passenger Survey and Silver Line Washington St 2005 Passenger Survey.

### *Ridership Forecasts*

In 1994, the project's Final Environmental Impact Study forecasted 24,300 daily trips on what was to become Silver Line Waterfront in 2010. This forecast did not include airport trips, which were not then part of the project. As we have seen, the actual ridership figure for 2006 was 11,006, about 4,070 of which were airport trips. Thus the actual ridership for Seaport-Area trips in 2006 of 6,936 is only 29% of the amount estimated for 2010. This is partly explained by the progress of development in the area; a good deal of what has been completed is outside the stations' catchment area, and much of the development closer to the stations is yet to be completed.



## **6. SYSTEM BENEFITS**

### **6.2 CAPITAL COST EFFECTIVENESS**

The capital cost of the Transitway facility, including land acquisition, design and engineering, construction, and overhead, but excluding vehicles and maintenance facility, was \$540 million. The length of the Transitway from South Station to World Trade Center is 1 mile. Thus the total cost of the project was about \$540 million per directional route mile.

The *total* project cost, including vehicles and the portion of the maintenance facility attributed to Transitway vehicles, was \$618.8 million. This can be annualized by assuming a discount rate and a project lifetime, as shown in Table 6-6. If we assume a discount rate of 5% and a project life of 50 years, the annualized cost of the project is \$34.2 million, or almost \$94,000 per day. None of this cost is covered by fares paid. The true average fare paid is a combination of the cash fares and the value of transfers and passes. The Central Transportation Planning Staff calculated the true average fare for 2005 (CTPS 2006). There was insufficient data to calculate separate values for the Silver Line route. Because the fare policy for Washington Street is similar to that for bus routes, and the policy for Waterfront is similar to rail routes, we use the average fares for "bus and trackless trolley" (\$0.53) and for "heavy rail and central subway" (\$0.93). The January 1, 2007 fare increase changed the fare structure, notably by eliminating a subway-only pass and offering a system wide fare for single trips. A new fare mix study will be required to determine the true change in average fares per route. In the absence of such a study, we apply the 25% average fare increase to the 2005 true average fares to arrive at an average fare for Washington Street of \$0.67 and Waterfront of \$1.15.

The 11,006 riders per day generate revenue of \$9,135 compared to operating costs of \$20,643 per day. Thus the net operating subsidy is \$11,505 per day, and the net total subsidy is more than \$105,000, or nearly \$10 per boarding. By comparison, a similar calculation for the Silver Line Washington Street project shows a net subsidy of \$0.73 per boarding.



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**Table 6-6: Annualized total costs per boarding, Silver Line Waterfront and Washington St**

|                            | Silver Line Waterfront | Silver Line Washington St | Notes  |
|----------------------------|------------------------|---------------------------|--|
| Total capital cost         | \$618,800,000          | \$27,290,000              |  |
| Annualized capital cost    | \$33,895,844           | \$1,494,857               | annualized at 5% for 50 years                                |
| per day                    | \$92,865               | \$4,095                   | (365 days/year)  |
| Daily operating cost       | \$20,643               | \$13,041                  |  |
| Daily passenger revenue    | \$12,657               | \$10,012                  | \$1.15/pass for Waterfront;<br>\$0.67/pass for Washington St |
| Net operating subsidy      | \$7,986                | \$3,029                   | operating cost per day, net of fares                         |
| Total subsidy per day      | \$100,851              | \$7,125                   | operating and capital  |
| Passenger boardings        | 11,006                 | 14,943                    | per day  |
| Total subsidy per boarding | \$9.16                 | \$0.48                    | \$/boarding  |

### 6.3 OPERATING COST EFFICIENCY

Operating cost efficiency is the unit cost to produce a unit of service output from a unit of service input. Operating efficiency is assessed according to the following transit performance indicators, typically used throughout the industry to measure service productivity and operating cost efficiency:

- Operating cost per vehicle hour (cost effectiveness)
- Operating cost per vehicle mile (cost effectiveness)
- Passengers per vehicle hour (service effectiveness)
- Average cost per passenger
- Net subsidy per passenger

These figures are calculated and shown in Table 6-7 for the Silver Line Waterfront, all branches combined, using the most recent data available from the MBTA. Please note that these estimates are based on the average unit cost of providing all bus service, without making adjustments for the higher unit costs of dual-mode, articulated buses.





## 6. SYSTEM BENEFITS

**Table 6-7: Operating Cost Effectiveness, All Silver Line branches combined, Winter 2007**

|   |          |                          |
|---|----------|--------------------------|
| Vehicle hours (including layover) per day | 197      |                          |
| Revenue vehicle hours per day             | 145      |                          |
| Revenue vehicle miles per day             | 1837.85  |                          |
| Operating cost per day                    | \$20,643 |                          |
| Boardings per day                         | 11,006   | as of spring 2006 survey |
| Cost per revenue vehicle hour             | \$142    |                          |
| Cost per revenue vehicle mile             | \$11     |                          |
| Revenue miles per revenue hour            | 12.7     |                          |
| Passengers per revenue vehicle hour       | 76       |                          |
| Passengers per revenue vehicle mile       | 6        |                          |
| Cost per passenger boarding               | \$1.88   |                          |
| Average fare collected per boarding       | \$1.15   |                          |
| Operating subsidy per boarding            | \$0.73   |                          |

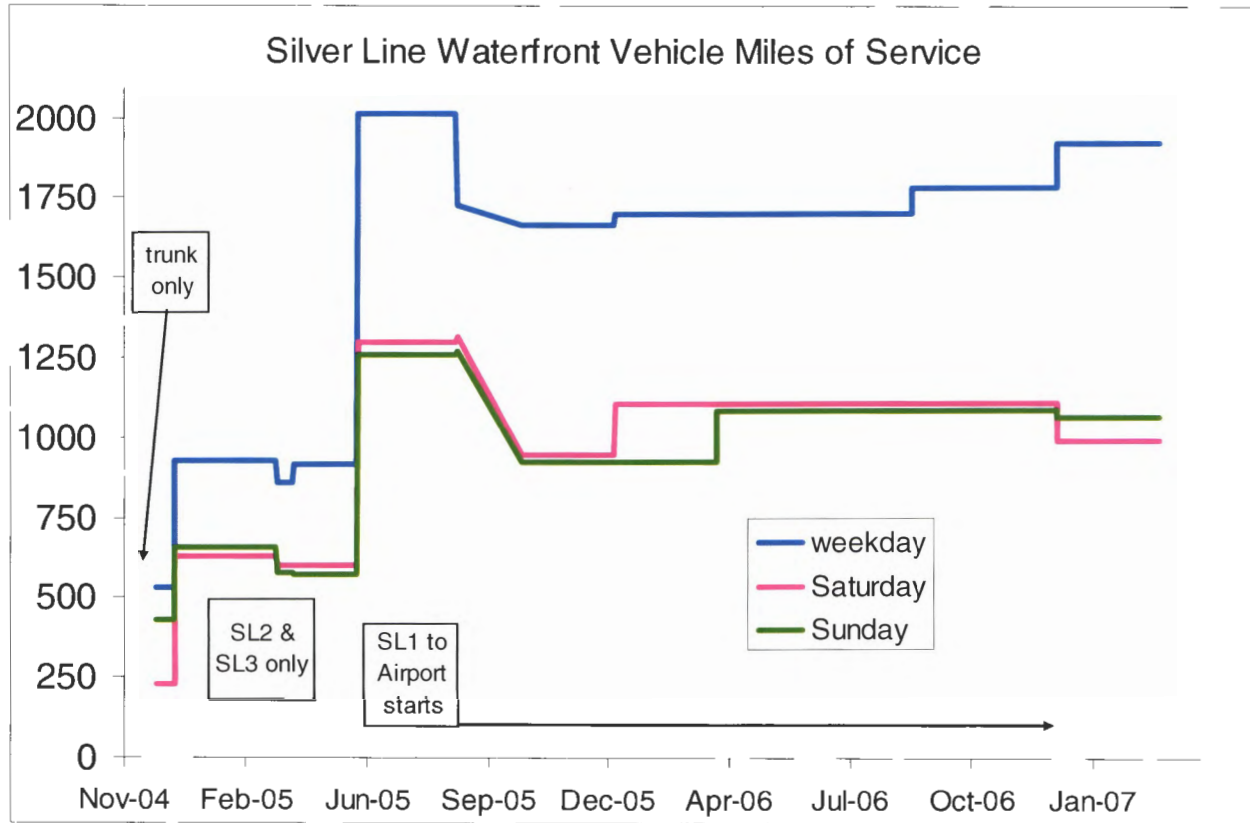
Although most transit service in the U.S. exhibits a peaked profile, the peaking is extreme on Silver Line service to the South Boston Waterfront (South Boston Waterfront), because most riders are commuting to jobs in South Boston Waterfront after taking other transit services to downtown (especially commuter rail to South Station). There is almost no commuting from residential riders boarding in South Boston and heading towards downtown. Thus although the average maximum load in the peak hour in the peak direction is 38 to 39 passengers, in the non-peak direction it is 6 passengers towards downtown in the morning and 3 passengers away from downtown in the evening (MBTA, Key Bus Routes Improvement Program, November 2006). This service profile makes the cost per peak-hour trip particularly high. As residential development progresses in the area this figure will go down, as the increase in non-peak direction ridership will not require additional service.

The history of vehicle miles of service provided is shown in Figure 6-3. Between December 17 and 31, 2004, the only service was trunk service on wire. For the first half of 2006, route SL1 was not operated except for limited Sunday service while the MBTA was waiting for the delivery of additional dual-mode vehicles. The big increase in vehicle service miles as of June 1, 2005 reflects the start of service for SL1. The amount of service provided has been periodically adjusted since then within a fairly narrow range.



## 6. SYSTEM BENEFITS

**Figure 6-3: Silver Line Waterfront, Vehicle Miles of Service**





## 6. SYSTEM BENEFITS

### 6.4 TRANSIT-SUPPORTIVE LAND DEVELOPMENT

The South Boston Waterfront is one of the fastest growing sections of Boston. It formerly consisted mostly of industrial facilities and parking lots, but is now in the process of becoming “a 24-hour neighborhood with a mix of industrial, residential, commercial, civic and retail uses” (South Boston Waterfront Public Realm Plan.) The recent surge of redevelopment in the area began with the Moakley Courthouse in 1998 and appears to have taken off with the announcement of construction of the Boston Convention and Exhibition Center, which opened in June 2004, and the opening of the Silver Line at the end of that year. Most recently, Mayor Thomas M. Menino has proposed moving Boston City Hall to the Waterfront, specifically Drydock 4 near Silver Line Way. All this development comes despite a “parking freeze” put in place by the Massachusetts Department of Environmental Protection, which caps the number of non-residential parking spaces in South Boston.<sup>7</sup> Although none of the development can be solely attributed to the Silver Line Waterfront project, the existence of the Silver Line is a key factor in siting development, and given the parking freeze most of the development would not be possible without it.



**Figure 6-4: Renaissance Boston Waterfront Hotel nearing completion (P. Schimek)**

<sup>7</sup> For details of the program, see the City of Boston Environment Department information on the South Boston Parking Freeze, <http://www.cityofboston.gov/environment/status.asp>.



## 6. SYSTEM BENEFITS

The following summarizes the land use situation in the area immediately adjacent to each station on the trunk route:

### *South Station*

South Station is a transit hub served by commuter rail, commuter and intercity bus, and the Red Line subway, as well as the Silver Line. There are many commuter-serving uses in station. A major tower is planned to be developed on the air rights over the station. As of March 2006, the proposed South Station Tower complex was to have a 40-story office tower (920,000 sq. ft.), nine-story office building (455,000 sq. ft.), 200-room hotel (220,000 sq. ft.), 150 condominiums (170,000 sq. ft.), and 900 parking spaces.



**Figure 6-5: South Station, with Silver Line information (P. Schimek)**





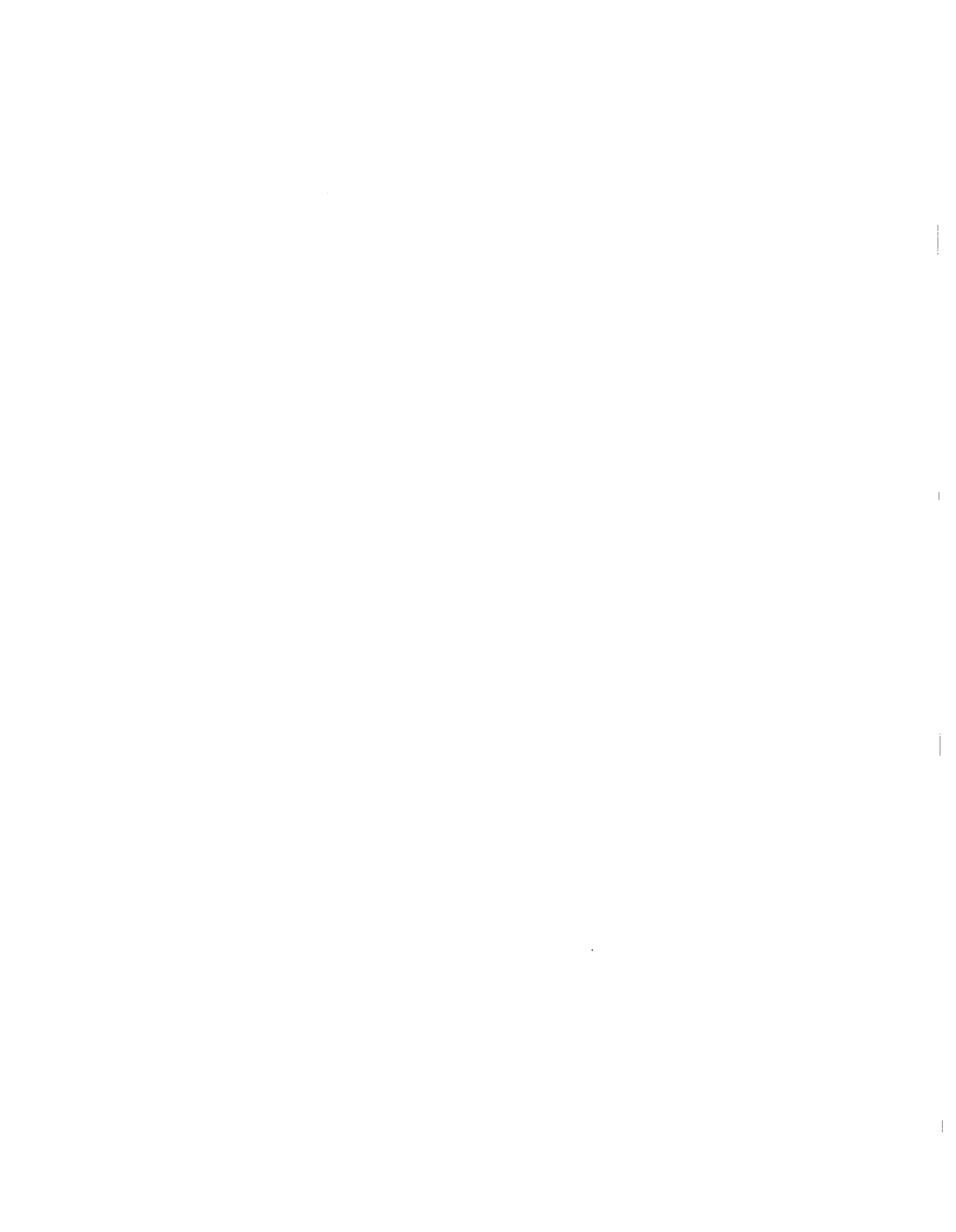
## 6. SYSTEM BENEFITS

### *Courthouse Station*

The area immediately adjacent to the Silver Line headhouses is surface parking, and is slated for development. Two temporary headhouses were built. These will be replaced as development occurs. The station was also designed to accommodate a second pair of entrances that could also enter directly into future development at the eastern end of the station.



**Figure 6-6: Temporary Courthouse station head house with adjacent land available for development (P. Schimek)**



## 6. SYSTEM BENEFITS

### *World Trade Center*

Most of the major new office developments in the South Boston Waterfront are within walking distance of this station. Massport owns that land around the station and is seeking to develop it for mixed uses.



**Figure 6-7: World Trade Center Station entrance, with Renaissance Boston Waterfront Hotel under construction in the background (P. Schimek)**



## 6. SYSTEM BENEFITS

### *Silver Line Way*

The Silver Line route runs directly under the Manulife Building (opened 2004) and stops adjacent to its parking lot. This parcel is owned by Massport, which is seeking to develop it, and will require a developer to incorporate a new station inside the project.



**Figure 6-8: Silver Line vehicles crossing D street, going under the Manulife building towards Silver Line Way (P. Schimek)**

As shown in Table 6-8, there have been about 2 million square feet of office and retail development in the South Boston Waterfront area since 1998. There have also been 1,200 apartments and 800 hotel rooms built, contributing roughly another 1.9 million square feet or 3.9 million total.<sup>8</sup> The ridership estimates in the Environmental Impact Statement were based on the assumption that there would be an increase of about 5 million square feet between 1986 and 2010 in the “low growth” scenario or 12 million in the “high growth” scenario. Given the 3,9 million

<sup>8</sup> This calculation assumes an average of 1,200 sf per apartment and 700 sf per hotel room.



## 6. SYSTEM BENEFITS

sf of development already completed to date, the area will soon meet the 5 million sf estimate for 2010. Table 6-9 shows the developments currently proposed, amounting to another 8.9 million square feet, for a total of 12.8 million—more than even the high estimate. The 8.9 million includes 2.9 million square feet at Fan Pier, with phased construction scheduled to start in late 2007 or early 2008. It does not include the 1.9 million square feet of open space that is planned.



**Figure 6-9: South Boston Waterfront land available for development, adjacent to Silver Line corridor (P. Schimek)**





## 6. SYSTEM BENEFITS

**Table 6-8: Major real estate development in the South Boston Waterfront, 1998-2006**

| Project  | Description  | Hotel Rooms | Apts. | Approx. size (SF 000) | Opening Date               |
|--|--|-------------|-------|-----------------------|----------------------------|
| John Joseph Moakley United States Courthouse   | 27 courtrooms, 40 judge's chambers, library, café, public spaces and offices   |             |       | 765                   | 1998                       |
| Seaport Hotel and World Trade Center           | hotel, restaurant and retail facilities, 250,000 square feet of meeting space, including a 418 seat amphitheater   | 427         |       | 250                   | 1998                       |
| East & West Office Buildings                   | 17-story office buildings on either side of the World Trade Center site  |             |       | 530<br>521            | East = 2000<br>West = 2003 |
| Manulife Tower (601 Congress St)               | 14-story office tower serves as Manulife / John Hancock's US Headquarters  |             |       | 420                   | 2004                       |
| Boston Convention and Exhibition Center (BCEC) | Largest convention facility in the northeast with 516,000 sf contiguous exhibit space, 160,000 sf meeting space, 300,000 sf function areas, and a 40,020 sf ballroom |             |       | 1700                  | 2004                       |
| Park Lane Seaport                              | Phase I - 13-floor apartment tower with 157 units<br>Phase II - 21-floor tower with 112 condos and 196 apartments; 20,000 sf retail                                  | 157<br>308  |       | 20                    | 2005<br>Summer 2006        |
| 15 Channel Center                              | 89 live/work artist studios and a theater in three buildings   | 89          |       |                       | No data                    |
| 25 Channel Center                              | New building with 76 residences on 12 floors   | 76          |       |                       | Fall 2005                  |
| 35 Channel Center                              | 44 lofts in a renovated historic building.   | 44          |       |                       | no data                    |
| Midway Studios                                 | Located at 15 Channel Center, includes 89 live/work artist studios and a theater in three buildings  | 89          |       |                       | no data                    |
| Westin Hotel Boston Waterfront                 | luxury hotel with a direct walkway to the BCEC, includes meeting space and retail and restaurant space; Phase II will be up to 330 more rooms                        |             | 793   | 132                   | June 2006                  |
| Intercontinental Hotel Boston                  | 21-story luxury hotel and condo complex includes 424 rooms and 130 luxury condos with 20,000 square feet of meeting space  | 130         | 424   | 20                    | Nov. 2006                  |
| Thomson Financial World Headquarters           | Conversion of a 6 story warehouse into an office building with basement at 44 Stillings Street   |             |       | 73                    | no data                    |
| Legal Sea Foods                                | Processing plant at 8 Seafood Way in BMIP  |             |       | 75                    | no data                    |
| Institute for Contemporary Art                 | The first new Boston art museum to open in almost 100 years includes four exhibit areas and a 325-seat theater.  |             |       | 65                    | Dec-06                     |
| Total  |  | 804         | 1,217 | 2,085                 |                            |
| Approximate average size (sf)                  |  | 1,200       | 700   | 1                     | TOTAL                      |
| Total Square Feet (thousand sf)                |  | 965         | 852   | 2,085                 | 3,902                      |



## 6. SYSTEM BENEFITS

**Table 6-9: Major real estate development planned for the South Boston Waterfront**

| Project   | Description   | Size (sf 000) | Opening Date   |
|---|---|---------------|--|
| Marriott Renaissance Boston Waterfront Hotel                  | Consists of 471 rooms hotel, 20,000 square feet of meeting space as well as retail and restaurant space.  | 500           | Broke ground Oct 2005<br>Opening Fall 2007                     |
| Boston Children's Museum                                      | Renovation with the addition of 23,000 sf located in Channel Center Planned Development Area  | 23            | Spring 2007  |
| Waterside Place (Summer/ D/ Congress/ World Trade Center Ave) | Mixed-use development to include upscale retail, hotel and condo tower, including department stores, restaurants and shops all on a deck over the WTC station   | 2,000         | Groundbreaking planned for late 2007 with opening in late 2009 |
| Fan Pier (28-70 Old Northern Ave)                             | Mixed use residential, retail, hotel and office development will total when complete.   | 2,900         | Scheduled to start late 2007 or early 2008                     |
| Pier 4(136-146 Northern Ave)                                  | Three new buildings with 385,000 sf of office space, 200-250 hotel rooms, approximately 200 housing units as well as retail, open space and parking   | 1,002         | Ground breaking 2007   |
| Congress Street Hotel (505 Congress – sausage site)           | 24 story extended stay inn and limited service hotel w/ 502 rooms and on site parking for 150 cars and approximately 8,000 sq. ft. of ground floor retail space   | 532           | Opening 2009   |
| Residences at 371-401 D Street                                | As of August 2000 was 715 new rental housing units – 585 market-rate rental units and 130 below-market home-ownership units in 4 buildings with approximately 724 parking spaces  | 690           | Construction beginning spring 2007 – 18 months                 |
| Waterside Crossing (Summer/D)                                 | 300-room hotel, 47,000sf grocery store, 150,000 sf retail anchor and 490 parking spaces<br>2.8-acre site  | 720           | Breaking ground in 2007 ; opening in late 2009                 |
| Boston Tea Party Ship and Museum (Congress St)                | Complete reconstruction of museum after fire adding a expansion barge into harbor and year-round use of the facility and increased public amenities.  | 19            | Opening spring 2008  |
| 346-354 Congress St   | Rehab of 2 existing buildings and infill of adjacent surface lot for the provision of 97 condominium units, including 4 artist live/work units, and ground floor restaurant space.  | 145           | no data  |
| International Cargo Center of New England                     | 305,000 square foot facility between Northern and Drydock Avenues in the Boston Marine Industrial Park (BMIP). Phase one is a 209,000 square foot warehouse and office space at 6 and 10 Drydock Avenue. Subsequently, new warehouse and office support will be built in place of the current building 239 Northern Avenue. | 305           | 2007   |



## 6. SYSTEM BENEFITS

|                          |  |       |                                  |
|--------------------------|--|-------|----------------------------------|
| Boston City Hall         | In December 2006 Mayor Thomas M. Menino proposed constructing a new City Hall on Drydock 4 in South Boston, within close proximity to the Silver Line Way station.   |       | Feasibility study in 2007        |
| 316-322 Summer Street    | Mixed-use residential development includes 86 residential units (11 affordable) and 8 artist live/work units. Also includes 15,500 square feet of retail and commercial space on the ground-floor along Summer and A St. | 115   | Construction began December 2006 |
| <b>TOTAL DEVELOPMENT</b> | (thousand sf)  | 8,951 |                                  |

### 6.5 ENVIRONMENTAL QUALITY

#### *Air Quality*

The introduction of new, lower emission transit vehicles to the corridor produces air quality benefits. The buses used are cleaner than older MBTA vehicles, but similar to other new vehicles in the fleet. According to the CTPS Passenger Survey, about 12% of Silver Line Waterfront riders previously used an automobile for the trip. With a base of 11,000 daily riders, this means about 1,300 car trips diverted, a small fraction of daily automobile traffic in the area. Therefore the indirect air quality benefits from diverted auto trips is likely to be small compared to the direct benefit of using low-emission buses and the indirect benefit of the induced trips taking the place of alternative trips that would have been by auto.

#### *Noise*

The dual-mode vehicles used for the Waterfront service have cooling fans for the diesel generator, the electric motor, and the HVAC system. This contributes to a relatively high level of noise, particularly on acceleration when operating on diesel power. The noise level was one reason cited by South Boston residents for the opposition to a Silver Line loop through the residential neighborhood.



## **7. CONCLUSIONS AND LESSONS LEARNED**

### **7.0 CONCLUSIONS AND LESSONS LEARNED**

#### **Construction complications**

The Silver Line Waterfront involved a complex construction project including land takings, coordination with other public and private development projects, and unforeseen difficulties such as the discovery of a large boulder in the alignment underneath the Fort Point Channel. After a five-year planning process, construction began in 1995. However, the full project opening was delayed from 2000 to 2005, resulting in a 10-year construction period. The construction difficulties led to an increase in total project cost from \$413 million in the original Full Funding Grant Agreement to the current estimate of \$619 million, representing a 50% increase.

#### **Rider benefits**

The running time from South Station to the furthest end of the South Boston Waterfront is not significantly faster by Silver Line than by previous MBTA local buses, according to published schedules, but the frequency of service and time it takes to transfer from rail rapid transit have improved dramatically. One reason for the modest effect on travel time is the increased number of passengers compared to the prior local service. Another is that the Transitway tunnel has a maximum speed of 25 mph in tunnel, with buses traveling frequently at lower speeds. The Silver Line provides a high level of reliability, as shown by the regularity of running time, particularly for airport trips. The quality of passenger information has improved greatly compared to previous service. Unlike the local bus service, there is no additional fare charged for those transferring to or from rail.

#### **Increased ridership**

We estimate that public transit ridership to Logan Airport increased by 24% due to the introduction of the Silver Line, taking into account that about half of Silver Line trips serving the airport would have previously been made by Blue Line. Transit ridership to the South Boston Waterfront doubled (98% increase) compared to our estimate of local MBTA bus and private shuttle ridership before Silver Line opening. CTPS ridership surveys show that 12.3%<sup>9</sup> of these new riders previously drove. In addition, 38% of the new riders did not previously make the trip, an indicator that the Silver Line is promoting growth in the area. As the South Boston Waterfront continues to develop, ridership will continue to increase.

#### **ITS**

The Silver Line Waterfront is equipped with Automatic Vehicle Location. Because contact with GPS satellites is not possible inside the tunnels, the dead-reckoning

---

<sup>9</sup> That is, 8% of the 65% who did not previously take an MBTA local bus or shuttle bus.





## **7. CONCLUSIONS AND LESSONS LEARNED**

devices augment the GPS receivers. This system is used to drive announcements of each stop, over loudspeaker and on LED sign, and to gather much of the running-time information used in this report. The Silver Line is not equipped with automatic passenger counters (APCs). As of 2007 the Silver Line uses automatic fare collection, as does the rest of the MBTA system. In addition to the customer convenience and running-time factors, this system also collects data that can be used for scheduling and planning. The three underground stations are equipped with LED signs that display schedule and other information. Finally, the line includes an automatic intrusion detection system to prevent unauthorized access to the tunnel, closed-circuit television, portal protection, and other, undisclosed security and anti-terrorism initiatives.

### **Costs**

The original planning documents from 1991 estimated a capital cost of \$284 million dollars. The final cost is approximately \$619 million. The cost escalation is due to many factors including:

- Higher than expected construction and acquisition costs.
- Additional design and engineering work.
- Under-estimated overhead costs.
- Price inflation following delays in construction.
- We estimate the total annualized (construction and operating) cost, net of fare paid, as \$9.16 per trip. For comparison, the equivalent figure for the Silver Line Washington Street is \$0.48.

### **Land Use**

We calculate that 3.9 million square feet of new development was opened for use in the South Boston Waterfront between 1998 and 2006, the period when the Silver Line construction was finishing and the first years of operations, compared to almost 5 million forecast for 2010. Another nearly 9 million square feet of development is currently planned. In addition, a major office tower is planned at South Station (which is served not only by the Silver Line but also by the Red Line subway, several commuter rail lines, and numerous regional and intercity buses). Station-area development closely linked to the Silver Line station entrances is planned for all of the other trunk line stations: Courthouse, World Trade Center, and Silver Line Way. The Silver Line project shows that developers will build in areas served by transit, even if the service does not have rails.

### **Identity and Image**

The Silver Line has been positively received by MBTA customers, most of who give it high ratings for service quality. Because it is on the system map and has a high degree of passenger information, people think it must be rail service. Even high-



## **7. CONCLUSIONS AND LESSONS LEARNED**

income riders, who generally avoid local buses, use the service. The riding public has responded to the increased service and higher level of quality by taking the Silver Line for numerous purposes including commuting trips, airport access, and special events along the Waterfront.



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## **List of Acronyms**

- AA/DEIS** – Alternatives Analysis/Draft Environmental Impact Statement
- APC** – Automatic Passenger Counter
- BMIP** – Boston Marine Industrial Park
- BRT** – Bus Rapid Transit
- CAD/AVL** - Computer Aided Dispatch/Automated Vehicle Location system
- CBRT** – Characteristics of Bus Rapid Transit for Decision-Making, August 2004
- CNG** – Compressed Natural Gas fuel used by transit buses
- CTPS** – Central Transportation Planning Staff
- CV** – Coefficient of Variation
- DEIR** – Draft Environmental Impact Report
- EA/NPC** – Environmental Assessment/Notice of Project
- EIS** – Environmental Impact Statement
- EOEA** – Massachusetts Executive Office of Environmental Affairs
- FFGA** – Full Funding Grant Agreement from the Federal Transit Administration
- FTA** – Federal Transit Administration
- FVM** – Fare Vending Machine
- GPS** – Global Positioning Satellite service used to help locate vehicles in system
- HVAC** – Heating Ventilation Air Conditioning
- ITS** – Intelligent Transportation System
- LED** – Light Emitting Diode used for passenger information signs
- Massport** – The Massachusetts Port Authority
- MEPA** – Massachusetts Environmental Policy Act
- MOS** – Minimum Operable Segment
- MPO** – Metropolitan Planning Organization
- NEPA** – National Environmental Policy Act
- PE** – Preliminary Engineering
- SBWTAC**- South Boston Waterfront Transit Advisory Committee
- Seaport TMA** – South Boston’s Transportation Management Association
- SL1, SL2, SL3** – Silver Line 1, 2, 3 bus rapid transit routes
- T** – Logo/branding term for the Massachusetts Bay Transportation Authority



**TSM** – Transportation System Management

**TSP** – Traffic Signal Priority

**TWT** – Ted Williams Tunnel

**URL** – web related term meaning Uniform Resource Locator and also Uniform Resource Identifier

**VNTSC** – Volpe National Transportation Systems Center, US DOT





# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC

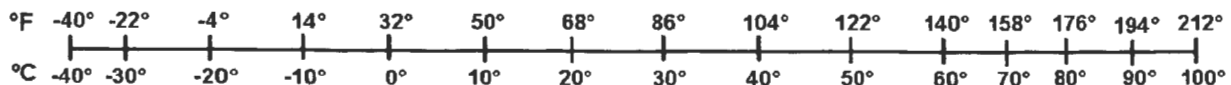
## METRIC TO ENGLISH

|   |  |
|---|--|
| <p><b>LENGTH (APPROXIMATE)</b></p> <p>1 inch (in) = 2.5 centimeters (cm)</p> <p>1 foot (ft) = 30 centimeters (cm)</p> <p>1 yard (yd) = 0.9 meter (m)</p> <p>1 mile (mi) = 1.6 kilometers (km)</p>   | <p><b>LENGTH (APPROXIMATE)</b></p> <p>1 millimeter (mm) = 0.04 inch (in)</p> <p>1 centimeter (cm) = 0.4 inch (in)</p> <p>1 meter (m) = 3.3 feet (ft)</p> <p>1 meter (m) = 1.1 yards (yd)</p> <p>1 kilometer (km) = 0.6 mile (mi)</p>   |
| <p><b>AREA (APPROXIMATE)</b></p> <p>1 square inch (sq in, in<sup>2</sup>) = 6.5 square centimeters (cm<sup>2</sup>)</p> <p>1 square foot (sq ft, ft<sup>2</sup>) = 0.09 square meter (m<sup>2</sup>)</p> <p>1 square yard (sq yd, yd<sup>2</sup>) = 0.8 square meter (m<sup>2</sup>)</p> <p>1 square mile (sq mi, mi<sup>2</sup>) = 2.6 square kilometers (km<sup>2</sup>)</p> <p>1 acre = 0.4 hectare (he) = 4,000 square meters (m<sup>2</sup>)</p>   | <p><b>AREA (APPROXIMATE)</b></p> <p>1 square centimeter (cm<sup>2</sup>) = 0.16 square inch (sq in, in<sup>2</sup>)</p> <p>1 square meter (m<sup>2</sup>) = 1.2 square yards (sq yd, yd<sup>2</sup>)</p> <p>1 square kilometer (km<sup>2</sup>) = 0.4 square mile (sq mi, mi<sup>2</sup>)</p> <p>10,000 square meters (m<sup>2</sup>) = 1 hectare (ha) = 2.5 acres</p> |
| <p><b>MASS - WEIGHT (APPROXIMATE)</b></p> <p>1 ounce (oz) = 28 grams (gm)</p> <p>1 pound (lb) = 0.45 kilogram (kg)</p> <p>1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)</p>   | <p><b>MASS - WEIGHT (APPROXIMATE)</b></p> <p>1 gram (gm) = 0.036 ounce (oz)</p> <p>1 kilogram (kg) = 2.2 pounds (lb)</p> <p>1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons</p>  |
| <p><b>VOLUME (APPROXIMATE)</b></p> <p>1 teaspoon (tsp) = 5 milliliters (ml)</p> <p>1 tablespoon (tbsp) = 15 milliliters (ml)</p> <p>1 fluid ounce (fl oz) = 30 milliliters (ml)</p> <p>1 cup (c) = 0.24 liter (l)</p> <p>1 pint (pt) = 0.47 liter (l)</p> <p>1 quart (qt) = 0.96 liter (l)</p> <p>1 gallon (gal) = 3.8 liters (l)</p> <p>1 cubic foot (cu ft, ft<sup>3</sup>) = 0.03 cubic meter (m<sup>3</sup>)</p> <p>1 cubic yard (cu yd, yd<sup>3</sup>) = 0.76 cubic meter (m<sup>3</sup>)</p> | <p><b>VOLUME (APPROXIMATE)</b></p> <p>1 milliliter (ml) = 0.03 fluid ounce (fl oz)</p> <p>1 liter (l) = 2.1 pints (pt)</p> <p>1 liter (l) = 1.06 quarts (qt)</p> <p>1 liter (l) = 0.26 gallon (gal)</p> <p>1 cubic meter (m<sup>3</sup>) = 36 cubic feet (cu ft, ft<sup>3</sup>)</p> <p>1 cubic meter (m<sup>3</sup>) = 1.3 cubic yards (cu yd, yd<sup>3</sup>)</p>    |
| <p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(x-32)(5/9)]^{\circ}\text{F} = y^{\circ}\text{C}</math></p>   | <p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(9/5)y + 32]^{\circ}\text{C} = x^{\circ}\text{F}</math></p>  |

## QUICK INCH - CENTIMETER LENGTH CONVERSION



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