Transport Canada | Transports Canada

98 B-line

# Bus Rapid Transit Evaluation Study

*September 29, 2003*

**Prepared by:**

IBI GROUP

TRANSLINK

September 29, 2003

Mr. Keenan Kitasaka, P.Eng.
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Dear Mr. Kitasaka:

***98 B-Line Bus Rapid Transit Evaluation Study***

We are pleased to submit this Final Report describing the results of our evaluation of TransLink's 98 B-Line Bus Rapid Transit service linking Vancouver and Richmond.

This project was funded jointly by Transport Canada, TransLink and IBI Group, and undertaken through Transport Canada's ITS Deployment and Integration Program.

The 98 B-Line Bus Rapid Transit service is one of North America's most successful implementation of bus rapid transit.  Latest state-of-the-art intelligent transportation systems are an integral part of the service, which contribute to shorter travel times, real-time "next bus" arrival times, and more reliable, on-time performance, all leading to higher ridership than the previous service.

This report describes the design and operation of the bus rapid transit service, the benefits and costs of this service, and guidelines for applications of bus rapid transit in other corridors and in other cities.

We hope that this document is helpful in promoting further applications of this exciting new public transit service.

Yours truly,

**IBI GROUP**

R. A. McNally, P. Eng.
Director

RAM/cm
VO-8262
Enclosure

# PREFACE

This project examines and documents the performance of TransLink's comprehensive bus rapid transit initiative, the 98 B-Line, with particular reference to the role of intelligent transportation systems. The report documents the benefits and costs of the service, and then presents guidelines for planning and design of bus rapid transit systems in other corridors in the Greater Vancouver Region, as well as other municipalities.

This project was undertaken by IBI Group in association with TransLink, and was jointly funded under Transport Canada's ITS Deployment and Integration Program.

The bus rapid transit service described herein is the 98 B-Line service, installed in the period 2000 – 2001, and serving the 16 km corridor between downtown Vancouver and downtown Richmond, with a connection to the Vancouver International Airport.

Questions or comments regarding the report or the ITS Deployment and Integration Program may be addressed to any of the following participants:

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# EXECUTIVE SUMMARY

*"Bus rapid transit is a truly visionary approach in providing high quality transit service essential to ensuring mobility and access for thriving communities…a world-class subway service on tires."*

This statement describes the new B-Line bus rapid transit services, TransLink's very successful and very cost-effective new transit service introduced into the Lower Mainland. TransLink has implemented three bus rapid transit (BRT) services: the 99 B-Line along Broadway, the 97 B-Line linking Coquitlam, Port Moody and Burnaby to the Millennium SkyTrain line, and the 98 B-Line linking Richmond, the Airport and downtown Vancouver; the 98 B-Line is the first BRT service that incorporates ITS technologies.

The 98 B-Line service from Richmond to Vancouver is one of the most comprehensive and successful bus rapid transit services in North America, incorporating a wide range of "rapid transit-like" features. This document describes the service, evaluates its performance, and provides guidelines for applying the service elsewhere. This work was jointly funded by Transport Canada, TransLink, and the participating consulting firm, IBI Group.

## Project Description

The 98 B-Line is a 16-kilometre bus rapid transit service connecting Richmond City Hall in the south, the Airport Station on the Vancouver International Airport lands, and downtown Vancouver. The 98 B-Line operates on arterial roads and incorporates a number of improvements to the roadways and the traffic signal systems to provide travel speeds competitive with auto travel. At its south end, the route originates at Richmond City Hall, follows No. 3 Road in Richmond, crosses the Moray Channel and the north arm of the Fraser River in the vicinity of the Airport lands, follows Granville Street and Seymour Street to the multimodal station at Waterfront, and then returns to Richmond via Burrard Street, Nelson Street, Howe Street and Granville Street through Vancouver, and No. 3 Road in Richmond. No. 3 Road has been reconstructed through joint Federal, TransLink and Richmond funding to provide exclusive median bus lanes over most of the length of the street, as well as enhanced landscape and street furniture improvements. Queue jump lanes on sections approaching the bridges over the Fraser River and exclusive curbside bus lanes through Vancouver permit B-Line buses to bypass chronic congestion locations.

Other transit priority features such as traffic signal priority when vehicles are behind schedule, and extensive traveler information systems such as 'next bus' announcements, along with architecturally designed stations and unique bus livery, together assist in branding the B-Line service as a new form of rapid transit.

The 98 B-Line service was implemented in stages, commencing in November, 2000. Full implementation involved an expenditure of approximately $52 million for vehicles, on-board transit management system, stations, busway, land, and traveler information systems, as well as a share of the new maintenance facility in Richmond. Full service commenced in the summer, 2001.

The purpose of this evaluation of the performance of the 98 B-Line is to assist TransLink in evaluating opportunities for BRT applications elsewhere, as well as to provide guidelines for other agencies and jurisdictions to implement BRT services. The evaluation considered users, owner/operator and the community at large. The sources of the evaluation data included travel time surveys, data from TransLink's automatic vehicle location system and from the traffic signal system, cost records, ridership surveys and customer surveys.

## User Benefits

Users of the 98 B-Line benefit from travel time savings, better on-time performance and improved service quality. Travel time savings were estimated to be approximately 20% reduction in time compared to previous services. On-time performance improved significantly over all sections of the system due to the real-time vehicle location tracking system and the traffic signal priority measures. Changeable message signs in the stations inform riders of the arrival time of the next bus. On-board audio and video displays announce next stops.

These improvements in travel time, on-time performance and enhanced traveler information result in a high rating of service quality as determined in customer surveys. In fact, the surveys indicate that approximately 23% of the users of the 98 B-Line were former car drivers or car passengers who have changed mode to ride transit.

An additional benefit of a shift in mode from auto mode to transit mode is reduced vehicle emissions. Based on a preliminary analysis of average vehicle trip lengths and occupancies, the shift from auto to transit associated with the 98 B-Line represents a reduction of 8 million vehicle kilometres per year by private automobile.

## Owner/Operator Benefits

The reduction in travel time and improvement in on-time performance results in reduced numbers of vehicles, reduced vehicle hours of operations and reduced capital and operating costs, all of which are benefits to TransLink. It is estimated that these improvements result in a reduction of vehicles and vehicle hours of operation of approximately 25%, a huge benefit to TransLink, while also providing much improved service.

One of the potential dis-benefits of providing priority to transit vehicles is the possible increase in delay to cross-street traffic. However, an analysis of the transit priority statistics indicated that the number of times that the buses require adjustments to the traffic signal phasing is relatively minor, resulting in a reduction of cross-street capacity by 1% in Vancouver and 6% in Richmond, the latter due to multi-phase signal operation in Richmond. These impacts are largely offset by capacity increases for traffic on the bus route.

An overall assessment of benefits and costs was estimated. Including user travel time benefits and capital and operating cost savings to TransLink, the benefits are estimated to be 30% higher than the costs, expressed on an annualized basis.

## BRT Implementation Guidelines

From this evaluation of the 98 B-Line, guidelines for implementing bus rapid transit in other corridors and in other municipalities are:

- The estimated transit ridership should be in the range of 500 – 1,500 persons per hour in the peak direction.
- The frequency of service should be between 6 and 20 vehicles per hour.
- Station spacing should be a minimum of 400 metres in high density locations and up to 1,500 metres in low density areas.
- Transit priority measures should be provided to achieve average speeds on arterial roads of approximately 25 km per hour, or 20 – 25% travel time reduction relative to local bus.

- Transit signal priority systems should be designed to minimize impact on cross-street general purpose traffic.
- The service should be designed as a unique quality and brand of service, through design of shelters, vehicle features and service characteristics such as traveler information.

A number of corridors in Greater Vancouver and in other regions, meet these guidelines for providing bus rapid transit service. This project has demonstrated that high quality bus rapid transit service can be implemented at relatively low cost and be very successful in attracting new riders.

## Project Achievements

In documenting the user and owner/operator benefits of the 98 B-Line BRT system, this evaluation study has also helped demonstrate how Transport Canada's ITS Deployment and Integration Program objectives have been achieved:

- **Objective #1:** Improve mobility and transportation efficiency, productivity, safety and security for passengers and freight. The 98 B-Line BRT has improved mobility by providing a fast and reliable rapid transit service between two of Greater Vancouver's largest municipalities.
- **Objective #2:** Increase tourism, trade and traffic flows on north-south and east-west corridor; The 98 B-Line BRT improves north-south connectivity by providing a connection to the Vancouver International Airport through the Airport Station in Richmond, as well as the Port of Vancouver.
- **Objective #3:** Improve intermodal connections, electronic commerce implementation and other strategic data exchange at transfer points and ports of entry. The 98 B-Line BRT provides links to the Airport Shuttle buses, 99 B-line along Broadway, 3 SkyTrain stations (Granville, Waterfront, and Burrard), SeaBus, and West Coast Express.
- **Objective #4:** Increase operational and regulatory efficiencies for system users and public agencies: The reduction in travel times and improvement in on-time performance results in reduced numbers of vehicles, reduced vehicle hours of operations and reduced capital and operating costs, all of which are benefits to TransLink and its customers.
- **Objective #5:** Reduce environmental impacts including air emissions and increase the use of alternative transportation modes. The improved air quality and environmental benefits realized by the shift in mode from auto to transit attributed to the much improved transit service is an important and significant contribution to the region's program to reduce greenhouse gases.
- **Objective #6:** Improve traveler information and data collection for more effective policy planning and operational management: The 98 B-line BRT has improved traveller information by providing real-time bus arrival information at stations, while also improving data collection through real-time monitoring of bus locations and schedule adherence.

In conclusion, the evaluation of the 98 B-Line BRT has demonstrated that BRT applications complemented by ITS technologies yield significant benefits in all of the areas targeted by the ITS Deployment and Integration Program. The benefits and implementation guidelines presented in this study not only help TransLink build on the success of the 98 B-Line to implement additional BRT services in the Greater Vancouver area, but also provides other regions in Canada with supporting information to implement BRT / ITS solutions – helping them meet their transportation goals and contributing to the realization of Canada's ITS Plan.

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## LIST OF EXHIBITS

## List of Acronyms

| | |
|---|---|
| APTS | Advanced Public Transportation System |
| AVL | Automatic Vehicle Location |
| BRT | Bus Rapid Transit |
| DGPS | Differential Global Positioning System |
| DMS | Dynamic Message Sign |
| DSRC | Dedicated Short Range Communications |
| GP traffic | General Purpose Traffic |
| GVTA | Greater Vancouver Transportation Authority |
| ICTS | Intermediate Capacity Transit Systems |
| ITS | Intelligent Transportation Systems |
| OTC | Oakridge Transit Centre |
| MDT | Mobile Data Terminal |
| MoT | Ministry of Transportation |
| RTC | Richmond Transit Centre |
| STC | Surry Transit Centre |
| TSP | Traffic Signal Priority |
| VLU | Vehicle Logic Unit |

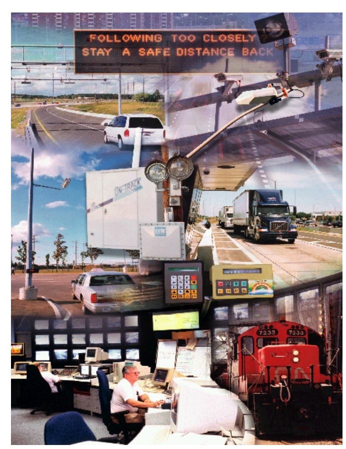
# 1.0 INTRODUCTION

In 1998, TransLink embarked on the design and implementation of a Bus Rapid Transit (BRT) service between the cities of Vancouver and Richmond. Branded as the 98 B-Line, this service was originally proposed by BC Transit as part of a 10-year transit service improvement plan in 1995. The plan included the development of BRT services in high demand corridors as a forerunner to the development of full rapid transit systems. The first of these lines went into effect in 1996 with the introduction of the 99 B-Line along Broadway-Lougheed. This service provides frequent, semi-express service between Lougheed Mall and the University of British Columbia, using high capacity, articulated buses with unique "rapid bus" livery, and marketed under the "B-Line" logo. Building on the success of the 99 B-Line, the customer services features of the B-Line services were expanded for the 98 B-Line, incorporating state-of-the-art BRT features such as the application of Intelligent Transportation Systems (ITS), including automatic vehicle location (AVL) and traffic signal priority (TSP), distinctive stations with real-time passenger information, high capacity articulated vehicles, and dedicated bus lanes along sections of the route.

The unique and "first-ever" attributes of the 98 B-Line BRT system have made it a great test-bed for a comprehensive evaluation of the BRT service and supporting systems, so that future BRT applications can benefit from the experiences gained in the implementation of the system, while helping to establish application guidelines that take into account benefits, costs, and impacts.

Accordingly, in August of 2000, TransLink and Transport Canada (under the ITS Deployment and Integration Program) commissioned a jointly funded evaluation study of the 98 B-Line system. This report presents the findings of this evaluation study.

## 1.1 TRANSPORT CANADA'S ITS DEPLOYMENT & INTEGRATION PROGRAM




In the fall of 1999, Transport Canada unveiled the *Intelligent Transportation System (ITS) Plan for Canada: En Route to Intelligent Mobility*. This Plan sets out the federal government's strategy for stimulating the development and deployment of these systems across urban and rural Canada. The goals are to maximize the use and efficiency of existing infrastructure and meet future mobility needs more responsibly. The ITS Plan provides leadership and support to advance the application and compatibility of ITS technologies to make Canada's multimodal ground transportation system safe, integrated, efficient and sustainable. The plan outlines five pillars of activity:

- Partnerships for Knowledge – the essential building block.
- Developing Canada's ITS architecture – a solid foundation.
- A multimodal ITS research and development (R&D) Plan – fostering innovation.
- Deployment and Integration of ITS Across Canada – moving forward.
- Strengthening Canada's ITS Industry – global leadership.

To accelerate the deployment, integration and interoperability of ITS across all modes, the federal government will provide support for strategic ITS deployment and integration to lever complementary public and private sector investment for projects that advance one or more of the following objectives:

- improve mobility and transportation efficiency, productivity, safety and security for passengers and freight;
- increase tourism, trade and traffic flows on north-south and east-west corridors;
- improve intermodal connections, electronic commerce implementation and other strategic data exchange at transfer points and ports of entry;
- increase operational and regulatory efficiencies for system users and public agencies;
- reduce environmental impacts including air emissions and increase the use of alternative transportation modes; and
- improve traveler information and data collection for more effective policy planning and operational management.

With the expectation that the 98 B-Line BRT has the potential to help contribute to achieving many of the above objectives, Transport Canada provided funding to support this evaluation study.

## 1.2 PROJECT PARTNERS

Transport Canada, TransLink, and IBI Group form the key funding partners in this project. The total value of this evaluation project was $175,000, funded as follows:

- Transport Canada $75,000
- TransLink $50,000 and $25,000 of in-kind services
- IBI Group $25,000 of in-kind services

## 1.3 STUDY OBJECTIVES

The objectives of this evaluation study are to:

- Estimate user benefits of the 98 B-Line BRT system (through measures such as reduced travel times, on time performance, etc.).
- Estimate operator benefits of the 98 B-Line system (through measures such as increased ridership, efficiency, etc.).
- Estimate impacts to other traffic (through measures such as general purpose traffic impacts, etc.)
- Develop guidelines associated with BRT costs and benefits, as well as corridor application guidelines, to be made available for evaluating and implementing BRT services and systems elsewhere.

# 2.0 PROJECT DESCRIPTION

Bus rapid transit is seen by the transit industry as a potential solution for providing high quality transit service at relatively low cost. Intelligent transportation systems are a vital component in providing the high quality transit service. The Greater Vancouver Transportation Authority (TransLink) is embarking on a program to implement bus rapid transit on its major routes, providing high quality, low cost transit service in major corridors where the costs of rail-based rapid transit cannot be justified, at least in the short term.

This section of the report presents an overview description of TransLink's transit service in the Vancouver region, and then describes the development and implementation of the 98 B-Line rapid bus service and the ITS elements which are subjects of this demonstration project.

## 2.1 OVERVIEW OF TRANSIT SERVICE IN THE GVRD

The Greater Vancouver Regional District (GVRD) comprises 22 municipalities and has a population of approximately 2.1 million people. Within the GVRD, the Greater Vancouver Transportation Authority (GVTA), publicly known as TransLink, is responsible for transit service, as well as the coordination, planning and funding of improvements to the 2,100 lane km and 3 bridges that comprise the Major Road Network (MRN), manages the Transportation Demand Management (TDM) and air emissions vehicle testing programs, and serves as the regional champion for other programs such as Intelligent Transportation Systems (ITS).

The transit system in the GVTA comprises over 1,200 buses (operated by Coast Mountain Bus Company, the District of West Vancouver, and contracted community shuttle operators), 210 automated light rail cars (SkyTrain operated by BC Rapid Transit Company), 34 commuter rail cars (operated by West Coast Express) and 4 passenger ferries on routes crossing the Burrard Inlet and the Fraser River. TransLink's transit system carries in excess of 129 million passengers per year, or over 60 transit trips per person, ranking third in overall ridership in Canada after Toronto and Montreal. TransLink's area of coverage is the largest of any major metropolitan city in Canada.

The GVTA is a highly successful governance model for providing regional transportation. The 15-member board is comprised of 12 members from the municipal councils in the region appointed by the GVRD, and 3 members appointed by the Provincial Government. The Board oversees the Authority and ensures regional representation. The Authority is a steering organization responsible for planning, policy and funding of transportation services and facilities in the region. The subsidiary companies and contracted private services operate the transit services, while the municipalities operate and maintain the road systems, with funding from the GVTA.

The Livable Region Strategic Plan (LRSP) prepared by GVRD sees transportation investment as a tool for encouraging desired land use patterns. The LRSP identifies five corridors for new

Intermediate Capacity Transit Systems (ICTS). More intensive urban development is to be encouraged in these corridors to support the region's land use vision.

SkyTrain, an automated light rail transit system, has been selected as a form of intermediate capacity transit system for the region. SkyTrain was introduced in 1986 linking downtown Vancouver and New Westminster. It has since been expanded to Surrey and more recently the Millennium Line opened from New Westminster to Coquitlam, Burnaby and Vancouver, to provide a total of 49 km of service, as shown in Exhibit 2.1. SkyTrain provides very frequent, high speed service along these main transportation corridors, carries peak direction loads of 8,000 persons per hour or more, at an average operating speed in excess of 40 km per hour. The system is fully grade separated, mostly elevated, with an underground section in downtown Vancouver. Since the system is automated and has a high average operating speed, the operating costs per passenger-km are relatively low. While the system has been very successful in attracting high ridership, high capital costs have limited its application to high ridership corridors.

Recognizing that limited capital funds are available, TransLink has focused on developing a form of rubber tired rapid transit called "rapid bus", marketed under the name "B-Line". These rapid bus services incorporate a wide range of transit priority measures to provide faster, frequent service in major transit corridors, along with some rapid transit-like features such as real-time traveler information. With the addition of substantial lengths of exclusive busway operation, such as on the 98 B-Line, the "rapid bus" service becomes more like the "bus rapid transit" services being introduced by transit planners as the new brand of high quality transit service.

Bus rapid transit is viewed as a first phase in the development of a full ICTS system which may include segregated busway, light rail transit, or automated light rail transit (SkyTrain). The B-Line services identified for the region include:

- Broadway / Lougheed 99 B-Line bus service between the University of British Columbia and Lougheed Mall, opened in 1996.
- Richmond / Airport – Vancouver 98 B-Line service, the subject of this project, started in August 2001.
- Coquitlam / Lougheed 97 B-Line service opened in September 2002.

Bus rapid transit is implemented in corridors that typically carry between 1,000 and 3,000 passengers per hour per direction. Above this volume range, separate right-of-way rapid transit services are considered more appropriate.

## 2.2 98 B-LINE SERVICE

The 98 B-Line service is most comprehensive in its service quality, and is the prototype of future B-Line services in the region. The 98 B-Line service provides many of the features of full rapid transit service, that is transit priority and real-time traveler information systems. The development of the 98 B-Line and the physical characteristics of the service are described following.

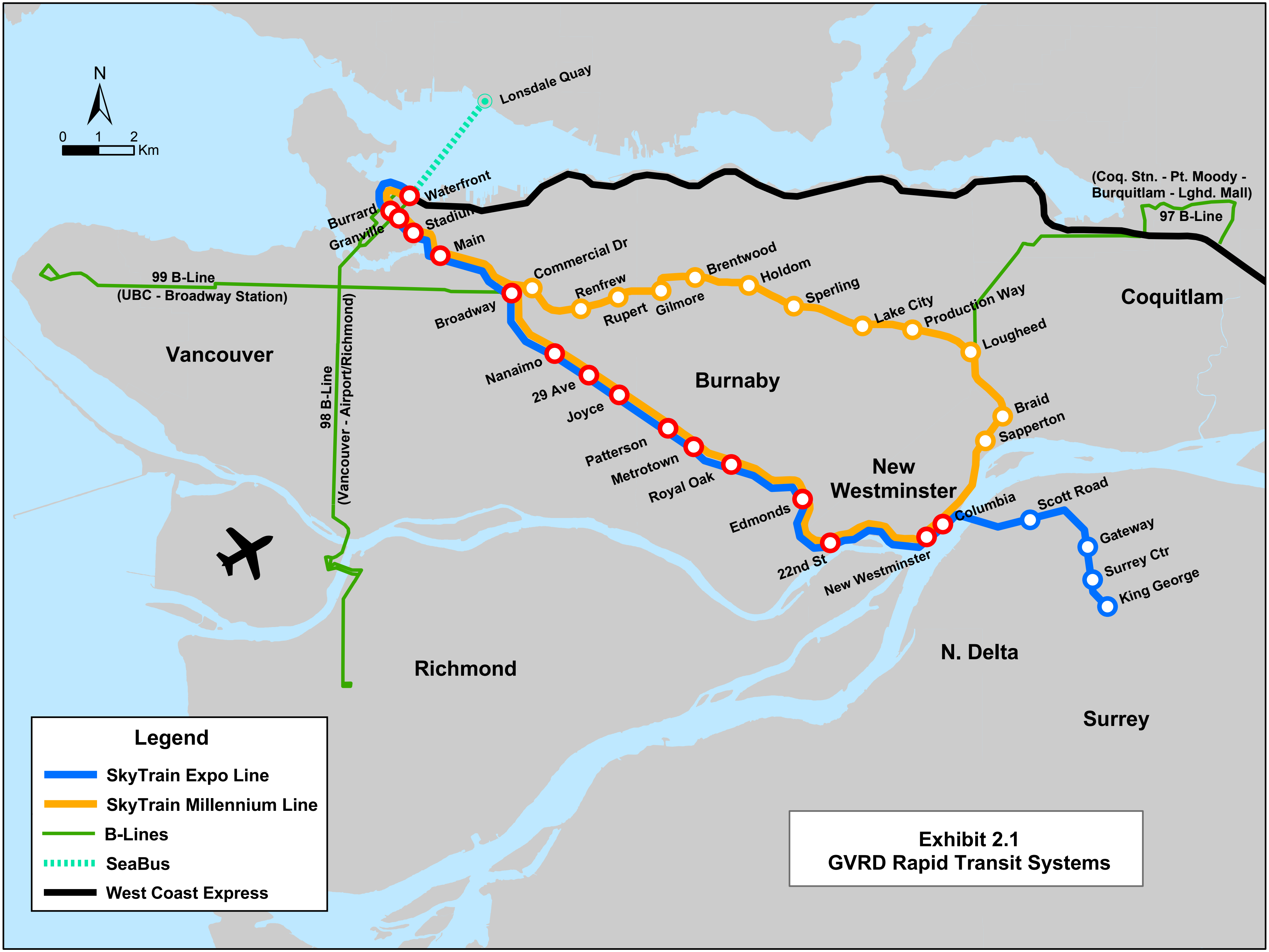



Exhibit 2.1
GVRD Rapid Transit Systems

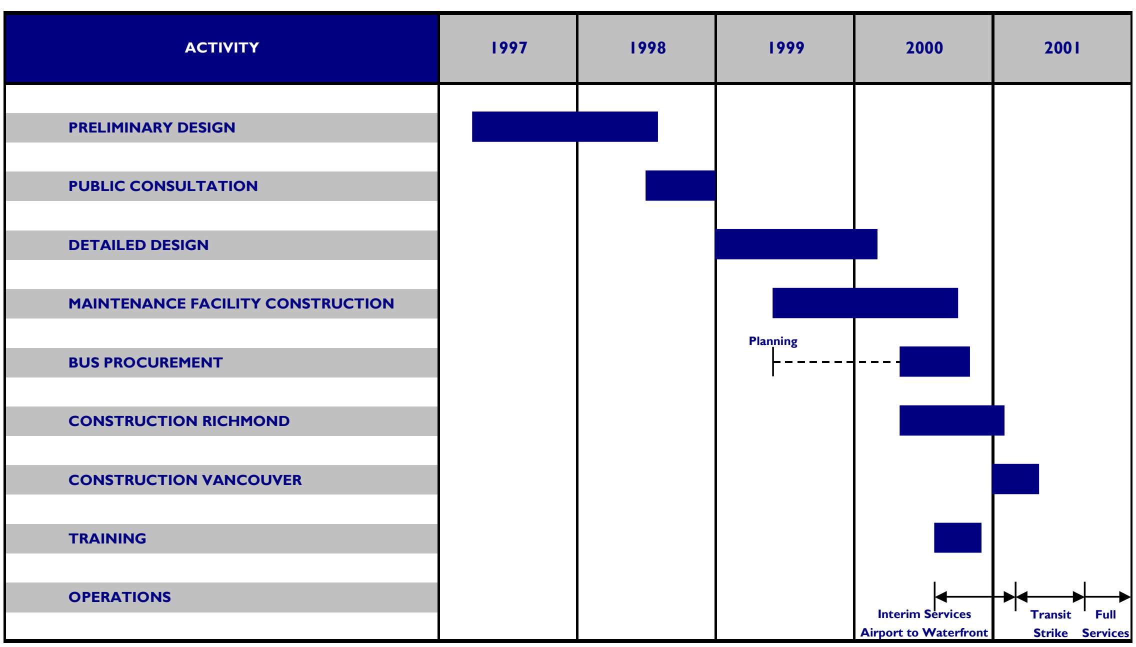
### *2.2.1 Background*

There were several phases in the implementation of the 98 B-Line:

- Preliminary Design (1997/98): Evaluated alternative routes and selected the preferred route and station locations.
- Detailed Design (1999/2000): Refined the route location and station locations, designed road and busway improvements, shelters and stations, traffic signal priority system and traveler information system.
- Construction (2000/01): Acquired land, constructed road and busway improvements, constructed bus shelters and stations, acquired vehicles, implemented traffic signal priority and real-time traveler information systems.
- Training and Service Commencement: Training commenced in December 2000, was delayed for 4 months due to a transit strike during the period April – July, 2001, and service commenced in August 2001.

Exhibit 2.2.1 presents the implementation schedule of the 98 B-Line service.

**Exhibit 2.2.1: 98 B-Line BRT System Implementation Schedule**




### *2.2.2 The Corridor*

The Richmond – Vancouver corridor is approximately 16 km in length, extending from Richmond City Hall at the intersection of No. 3 Road and Granville Avenue in Richmond, north to the Waterfront multimodal terminal in downtown Vancouver at the intersection of Seymour Street / Cordova Street. The 98 B-Line corridor is shown in Exhibit 2.2.2.


Exhibit 2.2.2 98 B-Line Route

This corridor accommodates many major trip generators, from Richmond in the south to Vancouver in the north, including:

- The southern 3 km along No. 3 Road is primarily retail and office commercial.
- The next section crosses the Fraser River to Sea Island and provides a connection to the airport transit services at the Airport Station.
- The 10 km section from the Airport Station to False Creek in Vancouver consists of the Marpole area retail commercial sector at the south end of Granville Street, and retail commercial at the north end of Granville Street between approximately 16th Avenue and 7th Avenue, with lower density, single family residential between the two commercial nodes.
- The Broadway Business District and connection to the 99 B-Line on Broadway.
- North of False Creek, the remaining 3 km section passes through downtown Vancouver's office and retail commercial section and the downtown south residential area.

Some of the major traffic generators on the corridor include:

- Downtown Vancouver accommodates approximately 130,000 employees.
- The hospital district east of the corridor between 12th Avenue and 35th Avenue accommodates over 40,000 health care and related jobs.
- The airport accommodates over 25,000 jobs, and projected to grow to 40,000 jobs over the next 20 years.
- The central area of the City of Richmond accommodates over 30,000 jobs.

Prior to introduction of the 98 B-Line, transit services in the corridor comprised a large number of Richmond-to-Vancouver express services, and a local service (Route #8) on the Vancouver portion of the corridor.

With the introduction of the 98 B-Line, some of the express services were restructured. After the full B-Line service was expanded to serve Richmond, the Airport and Vancouver, 5 peak period express buses were also provided to supplement service, along with continuation of the No. 8 local trolley service on Granville Street to downtown Vancouver. During the peak periods, the 98 B-Line service headway is every 5 - 6 minutes, reducing to 7.5 minutes in the mid-day and 15 minutes in the evening. The 98 B-Line service operates 7 days per week and up to 22 hours per day.

Weekday ridership in 2002 is estimated at 18,000 riders. The peak hour maximum load is approximately 1,000 peak riders or approximately 80 persons per bus.

### *2.2.3 Stations*

Station locations were selected to maximize user access and minimize user travel time. Stations were located generally at cross street bus routes, but at a minimum spacing of 400 metres in downtown Vancouver and downtown Richmond, and up to 2 km spacing in the lower density residential area of Vancouver between the Fraser River and False Creek.

Station stops are generally located on the far side of the intersection, which is consistent with TransLink's bus stop location policy. The far side locations are also consistent with the bus "check in / check out" distances associated with the traffic signal priority system. By exception, transit stations are located nearside of the intersection to facilitate transfers to other buses or access to major generators, or to recognize land availability.

Distinctive, architecturally designed shelters provide a high quality, rapid transit-like image for rapid bus. These shelters are well lit, incorporate glass walls for good visibility and minimizing security issues, but are also designed for low maintenance. Stations were sized to accommodate passengers based on forecast boardings at each station, using 0.4 $m^2$ per boarding passenger, plus an allowance for benches, trashcans, newspaper vending machines and, in the future, ticket vending machines for on street ticketing and all door loading. Examples of stations are shown in Exhibit 2.2.3.

**Exhibit 2.2.3: Stations on Busway on No. 3 Road, Richmond**


While it was desirable to install ticket vending machines at the stations, these were deferred because of fare enforcement issues, and also to reduce capital costs. In the meantime, passengers load by the front door, but eventually, when enforcement issues are resolved and ticket vending machines are installed, barrier-free, all door access may be provided.

The stations are equipped with "next bus" overhead customer information sign displays, indicating the time of arrival of the next two buses. This information is updated every 20 seconds from the central automatic vehicle location (AVL) system located in the central transit control room. This AVL system tracks the position of the buses using on-board GPS (global position systems) devices which communicate bus position to central control over the on-board radio system.

### *2.2.4 Route Selection*

During the Preliminary Design Phase, a number of alternative routings were examined for each segment of the service. Travel time surveys were undertaken along the different routes, as well as a review of traffic conditions, adjacent land uses and other criteria. The preferred routing is shown in Exhibit 2.2.2. This routing was estimated to result in end-to-end travel times of approximately 40 - 44 minutes during the peak periods for rapid bus, compared to as much as 50 minutes in the peak period for the express buses, and car travel times of 30 to 40 minutes.

In the Detailed Design Phase, more detailed investigation of travel times and routing options was undertaken using the microsimulation model VISSIM. The design features which were addressed included:

- The end-to-end travel time and the variability of travel times were estimated, to determine whether a layover at the Waterfront station is required, in addition to the layover at the south end at Anderson Road.
- A variety of traffic signal priority measures was examined to determine impact on bus travel times, as well as on general purpose traffic.
- Bus routing alignments along Smithe (contraflow lane) were compared to Nelson routing.
- The extent of busway operations in No. 3 Road was examined.

From this microsimulation, the following was concluded:

- The round-trip travel time would be approximately 80 – 85 minutes, which compares very favourably with the current schedule times.
- Traffic signal priority strategies, which provided conditional priority to the bus if the bus was behind schedule by 2 minutes or more, resulted in acceptable travel times for the bus, without seriously affecting general purpose traffic.
- The travel time variances along the route could be minimized as a result of the traffic signal priority capability, thus it was concluded that a layover at Waterfront Station would not be required, avoiding inconvenience to passengers continuing on past Waterfront Station.
- The routing along Nelson was chosen rather than along the contraflow lane on Smithe, since the traffic signal progression is favourable on Nelson rather than Smithe.

The chosen route includes 68 signalized intersections for the round trip. Most of the intersections in Richmond are multi-phase, while most of the intersections in Vancouver are two-phase signals. Signal priority measures were installed at all of the Richmond signals and all of the two-phase signals in Vancouver. The City of Vancouver, in conjunction with NOVAX, is attempting to install the signal priority measures at most of the remaining multi-phase signals. The traffic signal priority system is described in detail in Section 2.3.

### *2.2.5 Description of 98 B-Line Route*

Exhibit 2.2.5 shows the 98 B-Line route through Vancouver and Richmond, highlighting the transit priority measures.


**Exhibit 2.2.5**
**98 B-Line Route and Transit Priority Measures**

In Richmond, the 98 B-Line operates along No. 3 Road from Granville Avenue to Sea Island Way, much of it along dedicated median bus lanes referred to as the "busway". The service then crosses into Vancouver over the Moray Channel and Arthur Laing Bridges with a major transfer point at the Airport Station on Sea Island between the two bridges. The service benefits from a queue jump lane northbound to the Arthur Laing Bridge, and then a "bus only" lane from the north side of the bridge to 70th Avenue. In downtown Vancouver, the routing is via Seymour Street, where a daytime exclusive bus lane is provided, to Cordova Street at the north end of downtown where a multi-modal station and transfers are located at the Waterfront station, with connections to SkyTrain, SeaBus and West Coast Express. Southbound, the service follows Burrard Street to Nelson Street and Howe Street, benefiting by daytime curb side bus lanes on Howe Street, and then follows Granville Street across the Granville Street Bridge, through the South Granville retail area, and utilizes PM peak period southbound curb side bus lanes on Granville Street through the Marpole area, and a queue jump lane to the Moray Channel Bridge beyond the Airport Station. Peak travel times with these traffic priority measures are 40 minutes northbound in the AM peak hour and 46 minutes southbound in the PM peak hour, averaging approximately 24 km per hour.

The 2.5 km long busway in the most heavily congested part of No. 3 Road in Richmond provides significant travel time savings and trip reliability, compared to operation in mixed traffic. This busway was developed by reconstructing No. 3 Road to locate the busway in the median and relocate the general purpose traffic lanes to either side, utilizing the right-of-way available in the adjacent service roads, or through property purchase. The busway cost $12.4 million including $5 million for property acquisition. The City of Richmond contributed a further $2.2 million for landscaping the medians and creating a very attractive urban feature along the busway.

Traffic crossovers of the busway are only permitted at signalized intersections. In order to provide access to properties on both sides of the busway, U-turns are permitted at signalized intersections, in conjunction with the left turn phase. Traffic turns are permitted only under protected traffic signal phases, thus eliminating potential traffic conflicts. In the year following the implementation of the busway, the City of Richmond has advised that the accidents along the busway section have declined by approximately 20%, largely due to protected left turn phases at traffic signals. Some of the accidents have been attributed to driver confusion differentiating between the signal heads for the buses and the signal heads for the general purpose traffic; improvements have since been made.

### *2.2.6 Bus Exchanges*

Another feature that was investigated during the detailed design was the design of the bus exchanges. Two major bus exchanges were contemplated, one located on the airport lands at the intersection of Russ Baker Way, and a bus exchange at the south end in front of Richmond Centre.


The airport bus exchange provides transfers to airport shuttle services. These vehicles are owned and operated by TransLink and serve a variety of employment opportunities on the airport site.

At the southern terminus, on-street bus transfers both southbound and northbound are facilitated on No. 3 Road in the curb lanes. Southbound passengers may transfer to the local buses stationed at the curb immediately in front of the 98 B-Line buses. Similarly, northbound passengers may transfer from the local buses to the 98 B-Line bus on No. 3 Road in the vicinity of Anderson Road.

After the southbound 98 B-Line buses drop passengers at the Richmond Centre terminus, the buses then proceed to a layover location on Anderson Road, before entering service again by following a clockwise loop around via Granville Avenue to No. 3 Road North and the first northbound stop north of Anderson Road.

As mentioned earlier, consideration was given to a layover point at Waterfront station, the most northerly terminus of the service. However, since the northbound and southbound routes in downtown Vancouver are separated by up to four blocks, it was decided that the layover point at the Waterfront station should not be provided in order to avoid inconveniencing passengers who may be destined to points beyond the Waterfront station.

If a bus is well behind schedule, the operator is permitted to short turn the vehicle south of Cordova, permitting the vehicle to re-establish the desired headway. This short turn is not considered a major inconvenience to passengers.

### *2.2.7 Vehicles and Equipment*

The high ridership existing and forecast for the corridor determined that high capacity, articulated vehicles should be used for the service. Year 2006 ridership projections indicated a maximum load of 2,250 persons per hour in the peak direction in the corridor, on both BRT and express service. Based on an average capacity of 75 persons per bus seated and standing, and 90 minute route travel time, a total of 45 vehicles would be required, plus an allowance for spares.

The vehicles were acquired from New Flyer in Winnipeg. A vehicle specification was developed by TransLink staff and 44 buses were purchased, 28 of which were assigned to 98 B-Line service including spares, and the remainder were assigned to the express service.

The vehicles are low floor, articulated vehicles, with a raised portion in the back of the trailer section to accommodate the wheel wells and engine. The vehicles are wheelchair accessible, provide wheelchair ramps at the front door for wheelchair access, and provide a reverse facing stall behind the bus driver for wheelchairs. In addition, the vehicles carry racks for two bicycles. The cost of the vehicles is approximately $650,000 CAN each.

The 98 B-Line buses are equipped with on-board GPS units, tied to the Siemens Transit Master AVL system, as well as an onboard computer which relays the request for traffic signal priority from the central computer to the "in field" signal equipment. The buses are also equipped with onboard audio and visual displays announcing next station stop. This on-board equipment was installed by TransLink post-delivery of the vehicles from New Flyer.

### *2.2.8 Maintenance Facility*

Richmond bus service was previously operated out of Oakridge Transit Centre (OTC) in Vancouver. However, since the OTC was not equipped to service 60 foot articulated buses, and since the OTC facility was at capacity with no additional room for expansion, the Richmond Transit Centre was constructed to accommodate the new vehicles and to allow for additional expansion of the fleet. The RTC is located on 6.27 hectares (15.49 acres) in the Riverside Industrial Area of Richmond and serves as base for Richmond transit service, Richmond-Vancouver 98 B-Line service, and Orion V express coach service serving Delta, South Surrey and White Rock. Total cost of the project, including land acquisition, construction and all fixtures is estimated at $30 million. The RTC opened on Sept. 4, 2000

This facility accommodates 28 B-Line articulated buses and 175 other buses of various sizes. The portion of the cost of the RTC facility which should be allocated to the 98 B-Line buses is 20%, or $6 million.

### *2.2.9 Implementation of 98 B-Line Operations*

Following acquisition of the vehicles, a 2-month training period was undertaken, to familiarize drivers and dispatchers with the vehicles, equipment and routing.

A limited weekday service commenced in September, 2000 on the northern portion of the system from the Airport Station to downtown Vancouver, postponing commencement of the southern portion through Richmond until busway construction was complete. A transit strike in April – August, 2001 delayed commencement of the full operations until August 2001.

The operation from the Airport Station through Vancouver to downtown may be considered the "before – ITS" situation, since the traffic signal priority systems and the traveler information systems were not in operation during this initial period. Travel time information was obtained on selected days during this time period.

Shortly after completion of the busway in Richmond, the traffic signal priority system was installed and became operational. Although the original specifications called for traffic signal priority features which included green extension and red truncation, the specifications also called for phase insert, to avoid potentially long delays at multi-phase signals in Richmond. This feature was not incorporated since the City of Richmond felt that changing the usual sequence of signal phases may cause accidents, and the phase insert may increase delay to general purpose traffic. The phase insert operation should be considered further, possibly utilized when buses are significantly behind schedule, say more than 2 minutes.

## 2.3 ITS ELEMENTS

The 98 B-Line BRT system includes state-of-the-art ITS elements intended to enhance customer service as well as operations/management of the system itself. These ITS elements can be categorized as follows:

- **Transit Management:** The system incorporates Automatic Vehicle Location (AVL) and schedule adherence monitoring, supported by voice and data communications to the Surrey Transit Centre (STC) intended to optimize TransLink's efficiency in managing the 98 B-Line fleet of buses, as well as buses on other routes.
- **Traffic signal priority (TSP)**: The system allows buses to receive priority at traffic signals when running behind schedule, reducing the number of stops at intersections, as well as the amount of delay experienced at traffic signals, improving trip time reliability, while also contributing to reduced operating costs.
- **Real-time Passenger Information:** The system provides "next bus" arrival time information to customers at the 98 B-Line stations, updated in real time based on vehicle locations and schedule adherence – thus increasing passenger convenience and accessibility to the system.
- **Automated Voice and Digital Next Stop:** On board the buses, automated voice and digital displays provide "next stop" announcements to on board passengers.

The above subsystems are further described in the following sections.

### *2.3.1 Transit Management*

The 98 B-Line BRT transit management capabilities are provided for by Siemens' Transit Master™ system, which uses Differential Global Positioning System (DGPS) technology for increased AVL accuracy. This system includes both in-vehicle and central/dispatch components:

- **In-Vehicle:** Each bus is equipped with a PC based Vehicle Logic Unit (VLU) which collects and processes the GPS data, stores and manages pertinent schedule information, and facilitates data exchange with the STC. Buses are also equipped with a Mobile Data Terminal (MDT), connected to the VLU, which provides the bus operators with command and control capabilities. The MDT terminal displays the vehicle's schedule adherence status in real time, and displays messages sent from the STC; it also allows operators to send selected messages using smart buttons.


- **Central:** The STC acts as a base station for the 98 B-Line BRT, and includes all necessary components that provide the communication link between the dispatch centre and the mobile units. Central transit management and dispatch capabilities are provided through two dedicated workstations (dispatch consoles) located at the STC. The dispatch consoles provide access to the central information management and map display system that receives and transmits messages, monitors vehicle locations and schedule adherence, and records route information for later analysis and reporting. Transit controllers at the STC have the ability to quickly identify and respond to exceptions in schedules, routes, and pullins and pullouts, while maintaining data and voice communications with drivers.

### *2.3.2 Traffic signal priority*

The 98 B-Line BRT route encounters a total of 68 signalized intersections, of which 59 have the capability to provide priority to the 98 B-Line BRT vehicles upon request. TSP systems were not installed at 9 signalized intersections where cross-street general purpose and/or bus traffic volumes are high, possibly causing excessive delay to this traffic. Exhibit 2.3.2A presents a tally of the TSP capable intersections, while Exhibit 2.3.2B illustrates the location of these intersections along the route.

**Exhibit 2.3.2A: Tally of TSP Capable Intersections**

| | TSP Capable Intersections | | | | Total signalized Intersections Along Route |
|---|---|---|---|---|---|
| | **Northbound & Southbound** | **Northbound Only** | **Southbound Only** | **Total** | |
| Vancouver | **17 *** | **11** | **15** | **43** | **49** |
| Richmond | **16** | **0** | **0** | **16** | **19** |
| Subtotals | **33** | **11** | **15** | **59** | **68** |

** It should be noted that at the time of this evaluation, approximately 14 intersections within the Vancouver section were not capable with TSP due to contractor delays in implementing TSP software upgrades to the City's traffic signal controllers.*

The TSP capability of the 98 B-Line BRT system is provided by Bus Plus™ system supplied and installed by Novax Corporation. The TSP system uses Dedicated Short Range Communications (DSRC) to transmit priority requests from the vehicles to the roadside traffic signal controllers when buses are running behind schedule. In order to minimize the impact on cross street traffic, a "check in / check out" system for signal priority was devised to precisely locate the bus in the vicinity of the intersection. This system permits the priority call to be released as soon as the bus enters the intersection, rather than maintain the priority call for the full 15 seconds. This feature has convinced many traffic engineers that providing priority to transit vehicles does not necessarily seriously impact general purpose traffic.

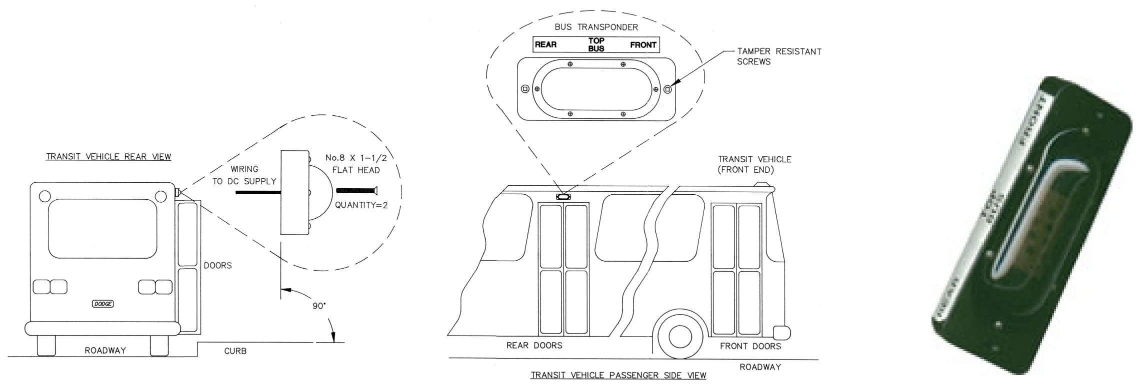
The following sections describe the bus detection method, traffic signal controller interface, and TSP strategies employed by the system.

#### 2.3.2.1 Bus Detection

The detection of buses requiring TSP is facilitated using a DSRC approach. Each BRT vehicle is equipped with a transponder that emits an infrared signal when priority is required. The transponders are connected to the AVL system via the in-vehicle VLU, and are turned on and off based on the schedule adherence status of the buses. The transponders are side-mounted above the middle doors of the buses. Exhibit 2.3.2C illustrates the transponder configuration.


**Exhibit 2.3.2. b**
**Locations of Signalized Intersections on 98 B-Line**

**Exhibit 2.3.2C: TSP Transponders**




The transponders are complemented by wayside detectors that receive the infrared signals transmitted from the BRT vehicles, and transmit them to the traffic signal controller. Each of the TSP capable intersection approaches is equipped with two wayside receivers, one located upstream of the intersection to "initiate" the priority request (check-in), and one located at the intersection to "cancel" the priority request (check-out). The "check-in" and "check-out" concept is intended to minimize the impacts of TSP to the cross street traffic.

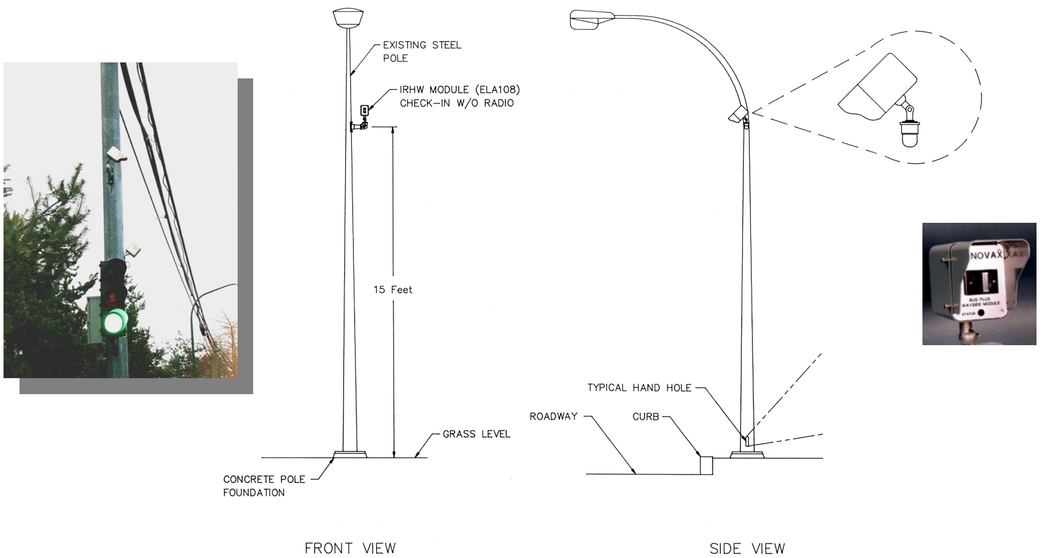
The location of the upstream wayside detectors ranges between 15 to 105 meters, depending on a number of factors, including:

- distance to the previous intersection or station (whichever is less);
- estimated bus operating speeds;
- allowable extension to the mainline green phase (as permitted by the municipal owner/operator of the affected traffic signal);
- duration of the cross-street Flashing Don't Walk (FDW) time.

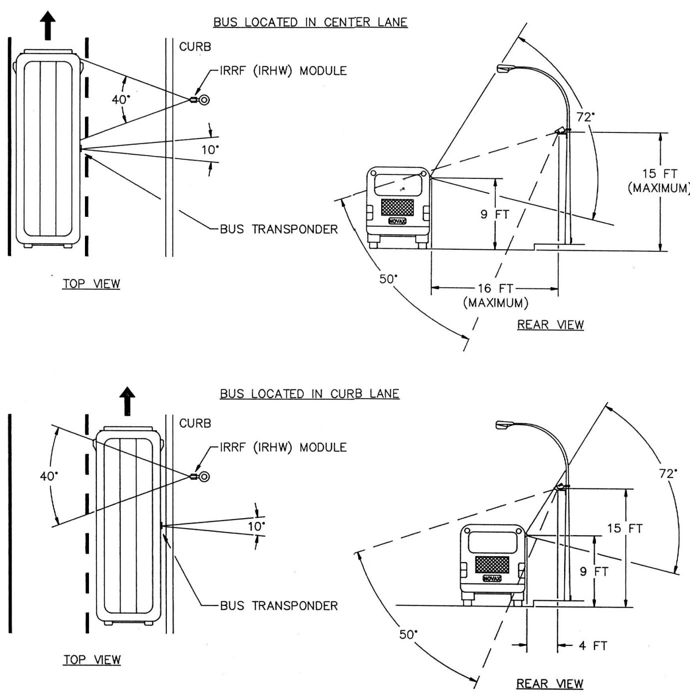
Exhibit 2.3.2D illustrates the configuration of these wayside detectors as typically mounted on existing luminaire or traffic signal poles. The check-in units transmit priority requests to the traffic signal controller interface (described in section 2.3.2.2) using either wireless RF communications or wire-line communications (depending on the particular intersection approach and the availability of conduits etc.). The check-out units are hard-wired to the traffic signal controller interface.

Exhibit 2.3.2E illustrates the relationship between the transponder signal and the wayside detectors.

## Exhibit 2.3.2D: Bus Detection Wayside Receivers




## Exhibit 2.3.2E: Bus Detection Zones



#### 2.3.2.2 Traffic Signal Controller Interface

The wayside detectors located along the two approaches to each signalized intersection interface with the traffic signal controller via a Master Unit installed in a small stand-alone cabinet near the signal controller cabinet. The Master Units decode the signals received from the wayside detectors and provide an output to the traffic signal controller in the form of a 12VAC signal.

The Master Units include an automatic time-out feature that cancels a priority call if the transit vehicle does not check-out during that time interval. A time delay feature is also supported, allowing for a delay between the time a priority call is received and actually transmitted to the traffic signal controller. This feature was used at intersection approaches with nearside BRT stations, where time delays were included to account for passenger dwell times.

#### 2.3.2.3 Supported TSP Strategies

The traffic signal controllers along the 98 B-Line route provide BRT vehicles with one of two basic TSP strategies upon receipt of a request:

- **Green Extension:** If the traffic signal controller receives a TSP request during the mainline green phase, it will hold the green phase until the approaching transit vehicle clears the intersection (i.e., checks out) or until a programmable maximum green extension time is reached. A maximum green extension time of 14 to 15 seconds has been used for all of the intersections along the 98 B-Line route, except in downtown Vancouver where 12 seconds has been used due to lower cycle lengths and signal coordination. Under this strategy, the sequence of signal displays remains the same, however, some time may be taken away from opposing phases following the green extension to stay in coordination. In this case the bus delay savings amounts to the time that would have been given to all other phases under normal operation (i.e., the cycle length minus the phase serving the bus).
- **Red Truncation (Early Green):** If the traffic signal controller receives a TSP request during the mainline red phase, it will reduce the amount of green time given to each opposing phase. This strategy is not very effective at intersections where the cross-street green times are governed by minimum walk and flashing don't walk (FDW) times, but can be highly effective at multi-phase intersections where other actuated movements such as protected left-turn phases exist. Again, the sequence of signal displays remains the same under this strategy. The bus delay saving is the amount of green time reduced from the opposing phases.

The original design of the system also included the provision of a "phase insert" TSP strategy at the intersections within the median bus-ways in Richmond; however, this strategy was not approved by the City of Richmond.

### *2.3.3 Real-time Passenger Information*

Real-time passenger information is provided to patrons both on-board the BRT vehicles and at the stations. The following types of information are available:

- **On-board Passenger Information:** The 98 B-Line BRT vehicles are equipped with Dynamic Message Signs (DMS) and audio enunciators for displaying/announcing the downstream station the vehicle is approaching. This information is based on real-time positioning information of the vehicles – available from the AVL system.
- **At-station Passenger Information:** The 98 B-Line BRT stations are equipped with DMS for displaying "next bus" arrival times based on real-time vehicle positions and speeds. This component of the passenger information system is facilitated by Siemens' OnStreet™ system. Each DMS provides a countdown timer for the next two 98 B-Line BRT vehicles approaching that station. The system uses the TransitMaster™ radio network to communicate with the signs, eliminating the need for other wireless or leased line communications with the stations. Exhibit 2.3.3 illustrates the sign type and configuration at the stations.

**Exhibit 2.3.3: Passenger Information DMS at Stations**


### *2.3.4 Mapping to the Canadian & Provincial ITS Architectures*

The functions and architecture of the ITS subsystems described in the previous sections align well with the Canadian ITS Architecture and the British Columbia provincial ITS Vision & Strategic Plan. Exhibit 2.3.4A provides a cross-reference between the market packages in the Canadian ITS Architecture and the ITS subsystems incorporated with the 98 B-Line.

**Exhibit 2.3.4A: Mapping to the Canadian ITS Architecture**

| Market Packages in the Canadian ITS Architecture | 98 B-Line ITS Subsystems |
|---|---|
| Transit Vehicle Tracking<br><br>This market package provides for an Automated Vehicle Location System to track the transit vehicle's real time schedule adherence and updates the transit system's schedule in real-time. Vehicle position may be determined either by the vehicle (e.g., through GPS) and relayed to the infrastructure or may be determined directly by the communications infrastructure. A 2-way wireless communication link with the Transit Management Subsystem is used for relaying vehicle position and control measures. The Transit Management Subsystem processes this information, updates the transit schedule and makes real-time schedule information available to the Information Service Provider Subsystem via a wireline link. | ▪ Transit Management using AVL |
| Multi-Modal Co-ordination<br><br>This market package establishes 2-way communications between multiple transit and traffic agencies to improve service co-ordination. Intermodal co-ordination between transit agencies can increase traveller convenience at transfer points and also improve operating efficiency. Co-ordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network. More limited local co-ordination between the transit vehicle and the individual intersection for signal priority is also supported by this package. | ▪ Traffic signal priority |
| En-Route Transit Information<br><br>This market package provides transit users at transit stops and on-board transit vehicles with ready access to transit information. The information services include transit stop annunciation, next vehicle arrival signs, and real-time transit schedule displays that are of general interest to transit users. Systems that provide custom transit trip itineraries and other tailored transit information services are also represented by this market package. | ▪ Real-time passenger information |

Exhibit 2.3.4B provides excerpts from the British Columbia ITS Vision & Strategic Plan, highlighting the plan's initiatives and projects that are supported by the 98 B-Line.

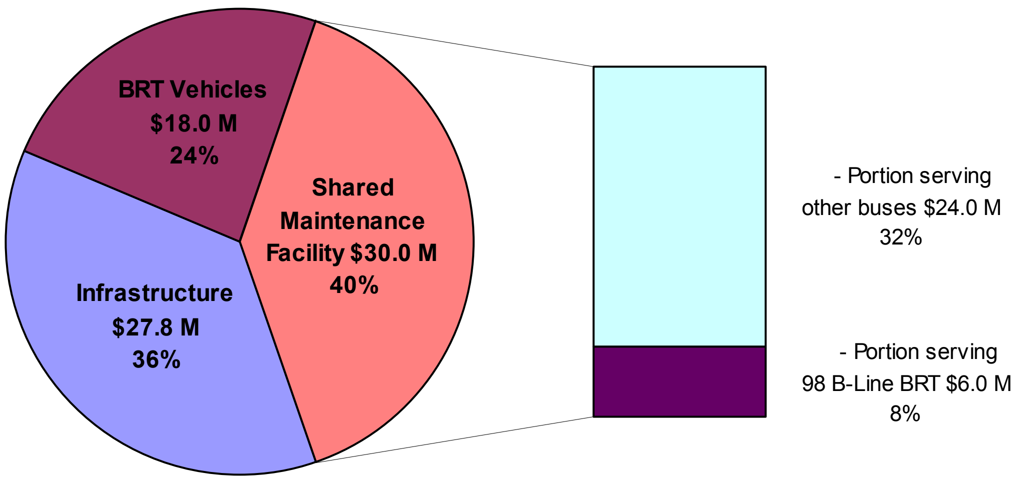
**Exhibit 2.3.4B: Relevant Initiatives & Projects in the BC ITS Vision & Strategic Plan**

| BC ITS Plan Initiatives & Projects | |
|---|---|
| **Initiative** | **Project** |
| **Initiative No. 8 Urban Transit Operations**<br>The purpose of this initiative is to deploy systems that improve the planning/scheduling, operations, maintenance and security of transit systems. Functions may include fleet management involving the integration of fleet based communications, monitoring of vehicles, their location and schedules, automatic passenger counting, real-time dispatching, and on-board security surveillance. These functions can be integrated with, and support, other initiatives pertaining to electronic payment systems, transit information, as well as transit priority. Systems deployed under this initiative must be designed to provide the transit operator with performance data to not only facilitate operation and management, but also evaluation and planning functions that support system management. High quality data (or lack of it) was cited as a major issue by many agencies during the needs assessment. | **APTS For Bus Rapid Transit And Major Transit Corridors**<br>Description: This project would include expanding or applying operations management, transit priority, and passenger information systems developed for the 98 B-line to other bus rapid transit applications or major transit corridors in the Lower Mainland or in the Capital Region District. Transit priority could range from simple green time extensions through to coordinated adaptive control for a number of closely spaced signals. Implementation of a comprehensive passenger information system would require an AVL system to provide real-time updates on transit vehicle location. |
| **Initiative No. 9 Transit Information**<br>The purpose of this initiative is to deploy systems that collect, manage, and disseminate transit information using a variety of media. Applications may include itinerary planning systems which allow passengers to plan total (origin to destination) trips for one or more available transit services; other applications can include real-time information systems for providing patrons with up-to-date information on scheduled transit vehicle arrival times, delays of routes, service disruptions and re-routings, via in-vehicle, wayside or terminal display systems, and through automated telephone messaging systems, cable television, and through internet web sites. This initiative can also include transit accessibility systems, which are directed towards providing improved transit information to passengers with disabilities via "talking signs", "talking kiosks", telephone information systems, and in-vehicle annunciators. | **Real-Time Schedule Information System**<br>Description: This project will take AVL system data and calculate revised schedule information as required for distribution via the different information channels in-place (internet, automated voice, regular telephone assistance). This project is an add-on to the other transit information systems and is not a stand-alone system. |

## 2.4 Project Costs

As illustrated in Exhibit 2.4.1A, the capital cost of implementing the 98 B-Line BRT system is approximately CDN$ 51.8 million, comprised of $18.0 million for a fleet of 28 buses, $27.8 million for infrastructure costs, and $6 million share of the $30 million maintenance facility.

**Exhibit 2.4.1A: Overall Project Costs (in CDN $ Millions)**




The following sections provide additional details of the above costs.

### *2.4.1 Infrastructure Costs*

The $27.8 million infrastructure costs for the 98 B-Line BRT system have been broken down into the following major elements:

| | | |
|---|---|---|
| • Design / Administration | $3.6 M | (13%) |
| • Construction | $10.4 M | (35%) |
| • Right-of-Way Acquisition | $5.0 M | (18%) |
| • Stations | $3.3 M | (12%) |
| • Service Management System | $4.6 M | (18%) |
| TOTAL | $27.8 M | (100%) |

Exhibit 2.4.1B provides a breakdown of these infrastructure cost elements. The sections that follow provide additional details associated with each category.

2.4.1.1 Design and Administrative Costs

The design and administrative costs include preliminary and detailed design of approximately $2.0 million, and TransLink administrative costs during the period 1998 – 2001.

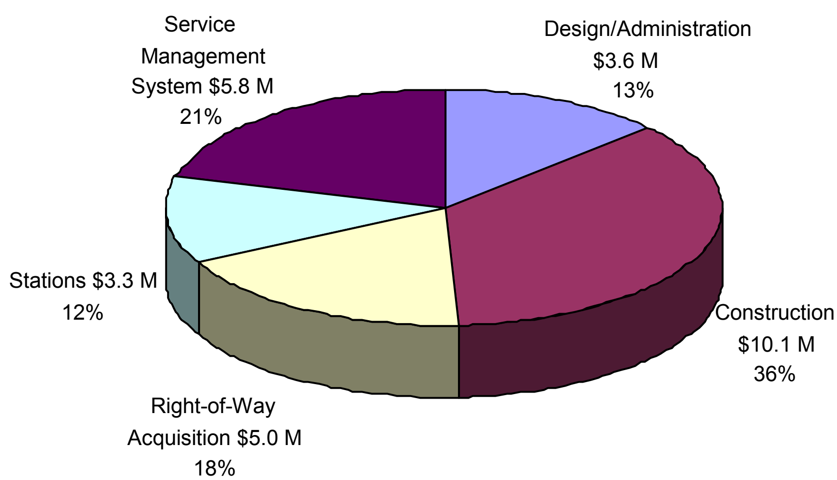



**Exhibit 2.4.1B: Infrastructure Costs**

2.4.1.2 Construction Costs

The $10.1M construction costs (presented in Exhibit 2.4.1B above) are all related to material pre-purchases, electrical, lighting, busway civil works, and landscaping etc in the City of Richmond, and can be broken down as follows:

- Richmond Electrical & Lighting at $2,460,000
- Richmond Busway (civil works, landscaping, etc.) at $7,640,000

Within the City of Vancouver sections, all the construction costs were related to the 98 B-line stations and traffic signal / priority upgrades. These costs are covered separately in Sections 2.4.1.4 Stations and 2.4.1.5 Service Management System.

2.4.1.3 Right of Way Costs

Additional right-of-way was necessary to accommodate the median busway in the section of No 3 Road, Richmond, between Westminster Highway and Sea Island Way. This 2.5 km section of the route was the only part in which property purchases were necessary.

In the section of No 3 Road south of Westminster Highway, a section of the parking area of Richmond Centre was obtained by dedication with the only cost being the legal fees associated with its registration.

The total cost of the properties required for the development of the dedicated median bus lanes was $5.0 million. This cost also covered some minor purchases from the BC Ministry of Transportation (MoT), work easements, consultant costs and an allowance for future claims for business loss.

2.4.1.4 Stations

The 98 B-Line BRT system includes a combination of median (in the City of Richmond only) and curb-side (in both Richmond and Vancouver) stations. Exhibit 2.4.1C provides a breakdown of the shelters portion of the station costs, excluding site services.

**Exhibit 2.4.1C: Breakdown of Station Costs**

| Station Location | Total Cost | No. of Stations | Average Cost |
|---|---|---|---|
| City of Vancouver | | | |
| ▪ Curbside | $ 1,184,000 | 20 | $ 59,000 |
| City of Richmond | $ 1,019,000 | | $ 56,000 |
| ▪ Curbside | ▪ $424,000 | 7 | ▪ $ 57,000 |
| ▪ Median | ▪ $480,000 | 8 | ▪ $ 60,000 |
| ▪ Airport Exchange | ▪ $115,000 | 2 | ▪ $ 58,000 |
| General | | | |
| ▪ Cost for services | $ 1,295,000 | 37 | $ 35,000 |
| **SUB TOTALS** | $ 3,500,000 | 37 | $ 93,000 |

2.4.1.5 Service Management System

The transit priority and transit management components of the 98 B-Line BRT system were tendered separately, as the Service Management System (SMS). Associated costs for these systems can be broken down as follows:

- **Transit Priority System:** The TSP system comprises the supply, installation, and testing of in-vehicle transponders, roadside detectors, and traffic signal controller interface units, as well as all installation related construction activities (such as conduit installation, wiring etc.). The total cost of the TSP system was $2.2 million, comprising $950,000 for the 44 signalized intersections in Vancouver, $350,000 for the 16 signalized intersections in Richmond, and $900,000 for other traffic signal-related improvements to enhance the transit priority capabilities, such as controller upgrades, new signals, vehicle detectors, etc.
- **Transit Management System:** The total cost of the central and onboard AVL equipment and associated installation, acceptance, documentation and training costs for the transit management system was $ 4.0 million, comprising $2.8 million for the central system, $500,000 for supply and installation of vehicle-mounted hardware in the 28 buses, and approximately $600,000 for radio communications and project management.

### *2.4.2 Vehicles*

TransLink procured 28 D60LS 18 metre articulated buses, manufactured by New Flyer Industries in Winnipeg, Manitoba, for the 98 B-Line. The delivery specification of the buses was standard to TransLink's fleet of articulated buses used on express, rapid bus and heavily trafficked routes. The equipment unique to the B-Line service, namely the AVL, communications and passenger information equipment, was installed in Richmond by the contractors for the SMS system. The purchase price of the buses, excluding the electronic equipment was $650,000 per vehicle.

### *2.4.3 Shared Maintenance Facility*

As noted previously, the RTC functions as a shared maintenance facility serving Richmond transit service, Richmond-Vancouver 98 B-Line service, and Orion V express coach service. Total cost of the project, including land acquisition, construction and all fixtures is estimated at $30 million. Based on accommodating a total of 250 buses, the per vehicle cost of this facility is $140,000 per standard size bus. The portion of the overall cost that is allocated to the 28 98 B-Line buses, allowing for the larger articulated size, is 20% or $6 million.

## 2.5 PLANNING LEVEL COST SUMMARY

Exhibit 2.5.1 presents a summary of the capital costs for implementation of the 98 B-Line, expressed on a unit cost basis.

**Exhibit 2.5.1: Planning Level Cost Summary**

| | |
|---|---|
| Busway | |
| ▪ Construction Cost per Lane km | $2.0 M |
| ▪ Land Cost per Lane km | $1.0 M |
| Stations | |
| ▪ Cost per shelter | $60,000 |
| ▪ Cost for services / platform | $35,000 |
| Traffic Signal Priority | |
| ▪ Cost per intersection | $35,000 |
| Automatic Vehicle Location System | |
| ▪ Central system | $2.8 M |
| Vehicles | |
| ▪ 18 m (60 ft.) articulated vehicles | $650,000 |
| On Board Transit Management System | |
| ▪ Cost per Vehicle | $18,000 |
| Maintenance Facility | |
| ▪ Cost per vehicle (articulated) | $210,000 |
| Design and Administration | 13% |

# 3.0 EVALUATION METHODOLOGY

An understanding of the goals and objectives of the 98 B-Line system provides a useful reference against which measured benefits and impacts can be compared. This section presents these goals and objectives, and identifies Measures of Effectiveness (MOEs) that can be used to measure their attainment.

## 3.1 98 B-Line Service Goals/Objectives

The fundamental goals and objectives of the 98 B-Line service include:

- providing fast and frequent service;
- providing improved customer service through reliability and convenience;
- inducing increased ridership;
- operating an efficient transit service relative to traditional bus routes.

## 3.2 Measures of Effectiveness

The MOEs for evaluating the 98 B-Line BRT system have been grouped into three main categories:

- Users
- Owner/Operator
- General Purpose Traffic

### *3.2.1 Users*

In order to assess the effectiveness of the 98 B-Line and ITS components of this service, it is important to understand the changes in route structure that have occurred as part of the implementation of this service. Prior to the introduction of the 98 B-Line, transit service in the Richmond / Vancouver corridor consisted of a local trolley bus service on Granville Street that extended from downtown Vancouver to the Marpole neighbourhood at the south end of Granville Street. This service, which continues to operate today, has many stops and relatively low operating speeds. The second component of the transit service in the corridor consisted of Richmond transit routes that operated in local service in Richmond and then as express services through Vancouver, with limited stops for pick-up and drop-off of Richmond passengers only. These routes did not provide any service for transit trips within Vancouver on Granville Street.

As part of the September 2000 start-up of the 98 B-Line, a limited weekday daytime service on this route was initially provided between downtown Vancouver and the Airport Station (with transfer service to the Airport terminals). This initial phase took place while construction of the bus lanes on No. 3 Road in Richmond and the implementation of TSP along the route were completed. During this time, most of the Richmond routes continued to operate as before. This initial phase of the 98 B-Line provided Vancouver residents with higher speed, limited-stop transit service for trips within Vancouver.

After the opening of the busway on No. 3 Road, the full 98 B-Line service was implemented (August of 2001). The frequency of the local trolley service was reduced slightly due to a shift in demand to the higher speed 98 B-Line service. Some of the express services between Richmond and Vancouver continued to operate during the peak periods; however, these services now provide stops on request at the 98 B-Line stops within Vancouver. During the off-peak periods, express services were truncated to Richmond City Centre and passengers were required to transfer to the B-Line.

Some of the key implications of the changes to the route structure in the corridor are as follows:

- Travel times for the before and after conditions are not directly comparable due to differences in routing and the number of stops;
- The route structure has added the requirement for transfers for some trips in the corridor. As a result schedule adherence and reliability have become more important factors;
- Stopping procedures within Vancouver have changed to provide Vancouver residents with higher speed transit services in the corridor. These added stops can have an impact on schedule reliability.

A number of measures of effectiveness were used to assess the impact of the TSP and AVL systems on 98 B-Line operations with respect to the users of the service. These include:

- **Travel times**: in order to assess the impact of the TSP and AVL systems, travel times collected during the initial phase of operations on the 98 B-Line service (pre TSP) can be compared with recent travel times based on AVL data over the section of the route operated during both phases (Airport Station to downtown Vancouver). Significant changes to travel times are not expected; however, the variability of the travel times should decrease. The theoretical impact on average travel times due to the benefits of the TSP system can also be assessed through a review of TSP log data.
- **Reliability of service**: reliability of service, particularly in an environment where transfers are required, can be assessed through a review of schedule adherence. The TSP and AVL systems should help reduce the variability in schedule adherence as well as bring the average schedule deviation closer to zero. In the before case, the calculation of schedule adherence statistics can include the previous Richmond express routes as well as the initial phase of 98 B-Line operations. The AVL system was used as the source of schedule adherence data for current operations on the 98 B-Line.
- **Customer satisfaction**: the final set of measures that can be used to assess the impact of the 98 B-Line on users are based on their response to customer satisfaction surveys conducted after the initial stage of implementation of the 98 B-Line and more recently once the full service and most of the TSP system were operational.

The above measures of effectiveness were used in evaluating service between Richmond Centre and downtown Vancouver, and between the Airport Station and downtown Vancouver. It is recognized that the benefits may vary somewhat for other types of trips – such as within Richmond only, or within Vancouver only, and with/without transfers.

### *3.2.2 Owner/Operator*

The 98 B-Line service yields a number of important operating benefits to the owner, TransLink and its operating subsidiary, Coast Mountain Bus Company. These benefits include:

- Vehicle Travel Time Savings
- Ridership Increases
- Operating Cost Savings

The measures used to estimate each of these benefits are outlined below.

#### 3.2.2.1 Travel Times

The benefit to the operator of increased speeds and reduced travel times is fewer buses and fewer bus hours to provide a fixed level of service. This measure is directly related to travel time. In this analysis, round-trip time was used as a measure of effectiveness. As noted earlier, there was no directly comparable "before" bus service. Rather, estimates were made of the "before" service if it was provided. Although travel time varies throughout the day, it was assumed that the difference in the estimated "before" and the measured "after" travel times would be constant throughout the day.

#### 3.2.2.2 Ridership

Increased ridership is a direct benefit to the owner/operator in terms of additional riders and additional revenue. Other benefits to the community and society associated with increased transit usage and reduced auto usage were also identified.

Estimated changes in ridership were obtained from customer surveys of the current 98 B-Line riders. These counts were validated by comparison of screenline counts at Granville Street / 70$^{th}$ Avenue, since before and after ride check data were not available.

#### 3.2.2.3 Costs

Costs include both vehicle capital costs and vehicle operating cost changes. These benefits were measured in terms of potential reduction in vehicle fleet and annual vehicle operating hours resulting from the faster speeds and reduced travel times to provide the service relative to providing the same amount of service operating at the "before" estimated travel speeds and times.

### *3.2.3 General Purpose Traffic*

GP traffic may be impacted by the operation of the 98 B-Line BRT system in the following ways:

- Some of the traffic travelling within the same stream as the 98 B-Line buses may benefit from the advantages of TSP; i.e., vehicles adjacent to a 98 B-Line bus that is receiving TSP will be able to also benefit from added green time.
- Cross-street traffic along the 98 B-line route will experience delays due to the reallocation of green time from the cross-streets to the mainline during priority routines.

- Traffic forced to access properties on the other side of the median busway (by making U-turns at the downstream intersection) will impact left-turning GP traffic by utilizing available capacity within the protected left-turn lanes.

Measurement of the impacts to GP traffic cannot be carried out using traditional methods, such as by comparing before and after peak hour delays – since the frequency and locations where TSP is requested varies from trip to trip (based on bus schedule and the selected schedule adherence threshold – which triggers priority). The most appropriate way to assess the impact to GP traffic as a result of TSP is using the TSP log data, which provide a comprehensive inventory of the time, location, and type of TSP requests and grants. The following MOEs have therefore been identified for measuring the impacts to GP traffic.

- **Frequency of TSP grants:** This MOE will capture the frequency at which TSP is granted within the AM, Mid-day, and PM peak hours relative to number of peak hour cycles that an intersection goes through. For example, an intersection that has a cycle length of 120s will cycle 30 times in an hour; if this intersection is observed to grant 10 TSP requests within that same peak hour, it can be concluded that during 10 out of the 30 cycles, the intersection experiences some disruption due to TSP.
- **GP Delay Penalty due to TSP:** This MOE builds on the previous by taking into account the magnitude of the disruption experienced by opposing traffic, as a result of the accumulated granting of TSP requests. Here, the GP delay penalty will be recorded for each intersection, within each of the AM, Mid-day, and PM peak hours. The GP delay penalty is measured in terms of reallocated "green time" from cross-street to mainline when TSP is activated.

These MOEs were applied in the evaluation methodology presented in Section 5.0

# 4.0 DATA COLLECTION

In support of the methodology and MOEs described in the previous section, this evaluation study included a comprehensive data collection program, including both before and post implementation data.

## 4.1 BEFORE IMPLEMENTATION DATA

The "before implementation" data collection covered the period before the start-up of the 98 B-line, as well as the period during which a limited B-Line service was provided between airport Station and Waterfront Station. The following data was obtained as part of this program.

- **Previous Studies:** All previous relevant studies and reports providing baseline performance statistics as collected during the project planning phases, such as traffic volumes and travel times.
- **Traffic Volumes:** All available traffic volume information as available from the cities of Vancouver and Richmond, as well as from the Ministry of Transportation.
- **Signal Timing Information:** All available signal timing information as available from the cities of Vancouver and Richmond, as well as from the Ministry of Transportation.
- **Ride-Check Data:** All available ride-check data associated with four related routes #401, #403, #406, and the #407 was collected from TransLink. The ride-check data was used to determine the travel times (station to station), schedule adherence, on time performance, and loading of these major bus routes.
- **Bus Travel Times:** Baseline bus travel time data was collected by IBI Group in March of 2001 to obtain samples of operating conditions prior to TSP capabilities being in place. These travel times were collected on the interim operation of the 98 B-line (i.e., between Airport Station and downtown Vancouver), prior to activation of the TSP capabilities.

## 4.2 POST IMPLEMENTATION DATA

Similar to the before implementation data, a number of sources and methods were used to obtain data representative of conditions after the implementation of the 98 B-line. Specifically, the following data was obtained as part of the post implementation data collection program.

- **Traffic Volumes:** All traffic volume information (available from the post implementation period) was obtained from the cities of Vancouver and Richmond, as well as from the Ministry of Transportation.
- **Signal Timing Information:** All new signal timing information (relevant to the post implementation period) was obtained from the cities of Vancouver and Richmond, as well as from the Ministry of Transportation.
- **Customer Satisfaction Surveys:** Over 600 on-board interviews were carried out to obtain customer satisfaction statistics. The interviews were carried out on-board the 98 B-line vehicles between February 10$^{th}$ and 23$^{rd}$. Northbound interviews numbered 302 and southbound interviews numbered 313. Passengers were interviewed during morning rush, mid-day, afternoon rush and evening periods and on the weekend. The interviews were designed based on TransLink's previous customer satisfaction surveys along this route, with additional questions added to gauge customer perception and satisfaction relative to system's ITS elements.

- **BRT Performance Statistics:** The 98 B-line service performance statistics were collected using the GPS/AVL capabilities of the transit management system. Specifically, TransLink provided IBI Group with the transit management system databases to extract the following:
    - The AVL database was used to obtain a large sample of 98 B-Line travel time statistics, from which the trip time reliability statistics were generated.
    - The bus location and schedule adherence data were used to obtain the 98 B-Line on-time performance and schedule adherence statistics.
- **Traffic Signal Controller TSP Logs:** Both the City of Vancouver and Richmond provided data logs of TSP requests and durations from their respective traffic signal controllers. The TSP log data were obtained for the week of February 10th, 2003.
- **Miscellaneous:** Various other data elements were are collected from TransLink such as available post implementation ridership data, as well as capital and operating cost information.

The post implementation program proved to be extremely effective due to the ITS elements in the system. Specifically, the GPS/AVL capabilities of the transit management system allowed the collection of a very large sample of bus performance statistics to be collected electronically without the need for field data collection (which can be labour intensive).

# 5.0 EVALUATION

The evaluation of the performance, benefits and impacts of the 98 B-Line is considered for users of the service, the owner/operator (TransLink and Coast Mountain Bus Company), and the general purpose traffic along the route.

## 5.1 USERS

User impacts are presented in terms of user travel times, reliability of service and customer satisfaction. Users include all riders on the 98 B-Line, including commuters, shoppers, tourists, students, etc.

### *5.1.1 Travel Time Variability*

Exhibit 5.1.1 below presents some relevant statistics for sampled northbound and southbound travel times between Airport Station and downtown Vancouver (for statistics presented in this section, "downtown Vancouver" is referred to as the intersections of Seymour Street and West Hastings Street for northbound travel and Burrard Street and West Hastings Street for southbound travel) from both before and after the implementation of the TSP system. As shown in the exhibit, the differences in the average travel times are very small, but the reduction in the variability of the travel times, as measured by the standard deviation, is significant in almost all cases.

**Exhibit 5.1.1: Travel Times Statistics, Airport Station - West Hastings Street**

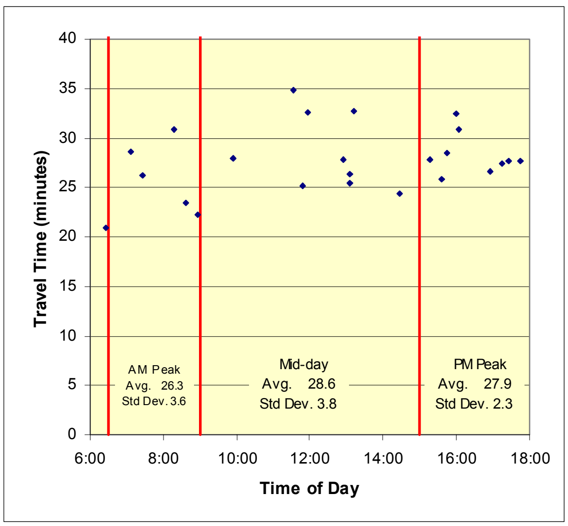
| | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | AM Peak (6:30-9:00) | Mid-day (9:00-15:00) | PM Peak (15:00-18:00) | AM Peak (6:30-9:00) | Mid-day (9:00-15:00) | PM Peak (15:00-18:00) |
| **Before** | | | | | | |
| Average (minutes) | 26.3 | 28.6 | 27.9 | 29.1 | 30.9 | 36.8 |
| Standard Deviation | 3.6 | 3.8 | 2.3 | 3.3 | 5.1 | 3.8 |
| Sample Size | 5 | 9 | 10 | 7 | 10 | 6 |
| **After** | | | | | | |
| Average (minutes) | 27.3 | 28.5 | 28.4 | 30.5 | 32.5 | 34.2 |
| Standard Deviation | 1.9 | 2.3 | 2.4 | 2.0 | 2.6 | 2.6 |
| Sample Size | 8 | 61 | 27 | 104 | 219 | 151 |
| F-test value | 0.13 | 0.02 | 0.97 | 0.04 | 0.00 | 0.15 |

The final row in the table presents the F-test value for the two samples. This value measures the statistical significance of the differences for each pair of standard deviations (before and after). The lower the value, the greater the likelihood that the variance of the two samples is different. The results suggest that the TSP system (in combination with the AVL system), has helped to make travel times less variable throughout most of the day in both directions, reducing variability by 40 – 50%. This is particularly true during the mid-day period when on-street parking affects travel speeds in the downtown and south Granville areas. The minor increase in AM Peak average travel times (although not significant) may be due to schedule inefficiencies, increased dwell times, or intersections where TSP is not installed yet.

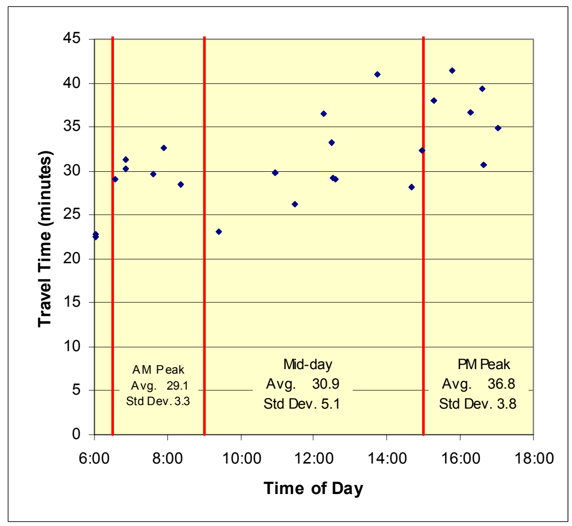
The variability of travel times by time of day is illustrated in Exhibit 5.1.2. Separate graphs are presented for the northbound and southbound directions for both before and after the implementation of the TSP system. The graphs illustrate how travel times variability within a time period is typically greater than the variability between time periods. In the case of southbound travel times after the implementation of the TSP, there is a discernable pattern with travel times increasing by time of day due to increasing road congestion in the afternoon and early evening. This pattern is recognizable given the large sample size obtained from the AVL system.

**Exhibit 5.1.2: Travel Times by Time of Day, Airport Sta. – West Hastings Street**

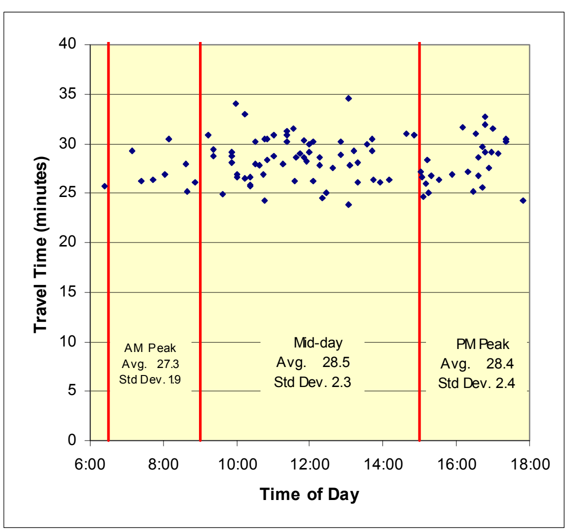
**TRAVEL TIME NB AIRPORT TO WEST HASTINGS WEEKDAYS BEFORE TSP**



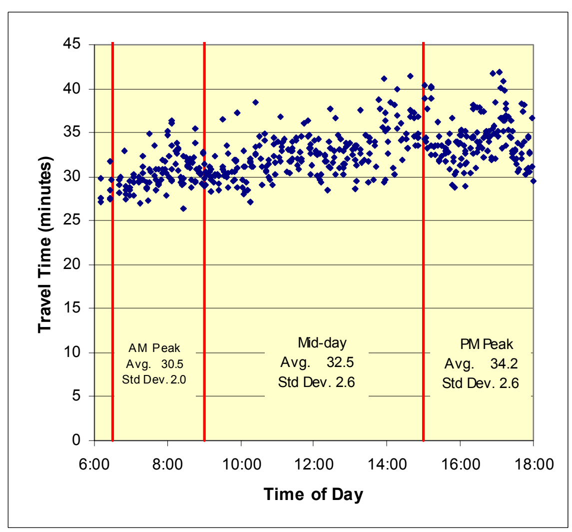

**TRAVEL TIME SB WEST HASTINGS TO AIRPORT WEEKDAYS BEFORE TSP**




**TRAVEL TIME NB AIRPORT TO WEST HASTINGS WEEKDAYS AFTER TSP**



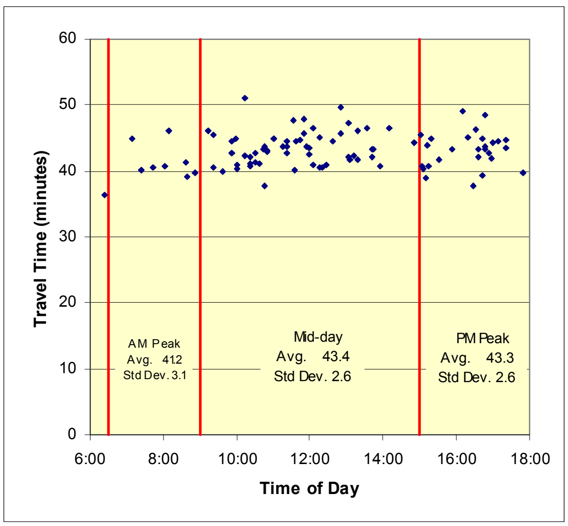

**TRAVEL TIME SB WEST HASTINGS TO AIRPORT WEEKDAYS AFTER TSP**



Using the AVL data, it was also possible to calculate travel times between Richmond Centre and downtown Vancouver during the data collection week in February 2003. Travel times over the full route show similar patterns of variation as the times over the shorter section, as illustrated in Exhibit 5.1.3.

Transit travel times were also compared with travel times for general purpose traffic in the same corridor. A limited number of travel time surveys were undertaken during the peak periods. The comparative statistics between auto and transit travel times are presented in Exhibit 5.1.4. Travel times by auto are faster; however, the variability as measured by the standard deviation is greater. This greater variability is statistically significant during the AM peak period. Transit travel times are very competitive with auto travel times in the northbound direction during the PM peak period.

**Exhibit 5.1.3: Travel Times by Time of Day, Richmond Ctr. – West Hastings Street**



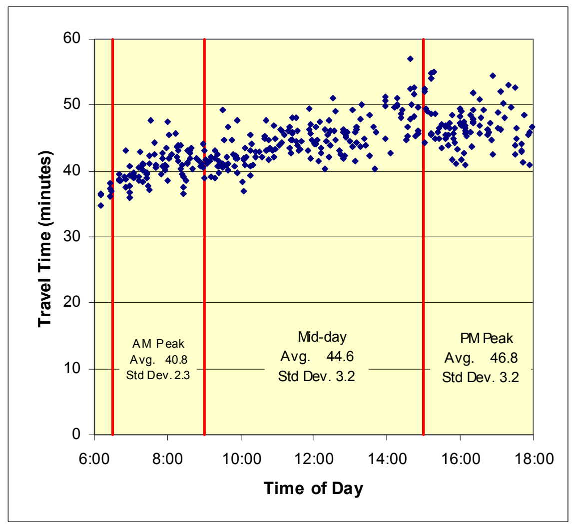




**Exhibit 5.1.4: Auto versus Transit Travel Times Statistics**

| | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | **AM Peak** (6:30-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) | **AM Peak** (6:30-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) |
| **Auto** | | | | | | |
| Average (minutes) | 28.9 | | 42.8 | 30.2 | | 39.2 |
| Standard Deviation | 5.3 | | 3.3 | 4.3 | | 3.7 |
| Sample Size | 13 | | 10 | 15 | | 13 |
| **98 B-Line** | | | | | | |
| Average (minutes) | 42.1 | 43.5 | 43.0 | 40.6 | 44.7 | 46.8 |
| Standard Deviation | 2.8 | 2.5 | 2.7 | 2.5 | 3.2 | 3.2 |
| Sample Size | 9 | 60 | 27 | 92 | 167 | 91 |
| F-test value | 0.08 | | 0.38 | 0.00 | | 0.41 |

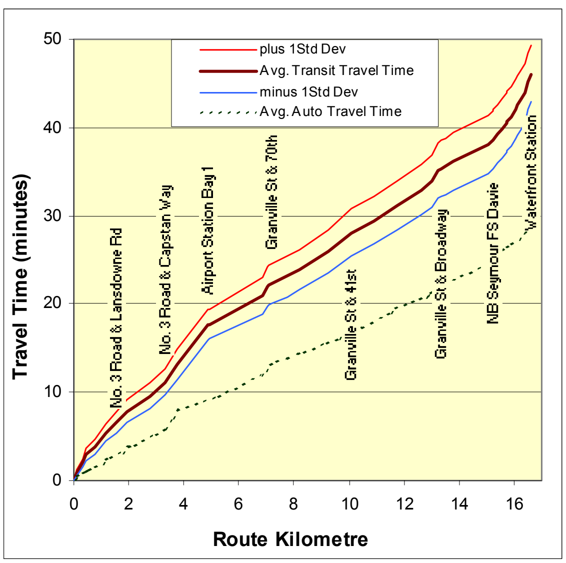
The AVL data was also used to generate a space-time plot of the average travel times along the route during peak periods. These graphs are presented in Exhibit 5.1.5. The average travel time profiles for the sample of auto trips in the corridor are also presented in the graphs.

As illustrated in the exhibit, locations with relatively slower speeds during the AM peak period in the northbound direction include: No. 3 Road in Richmond south of the bus lanes; approaching Airport Station; in Vancouver in the area of Granville and Broadway; and in downtown Vancouver. These localized areas of delay may be indicative of other problems causing congestion that may require engineering improvements. However, although the corridor includes these congestion hotspots, TSP allows the vehicles to make up this lost time elsewhere in the network. Auto travel times through Richmond are noticeably faster; this may result from the relatively close station spacing in Richmond and the frequent transit stops.

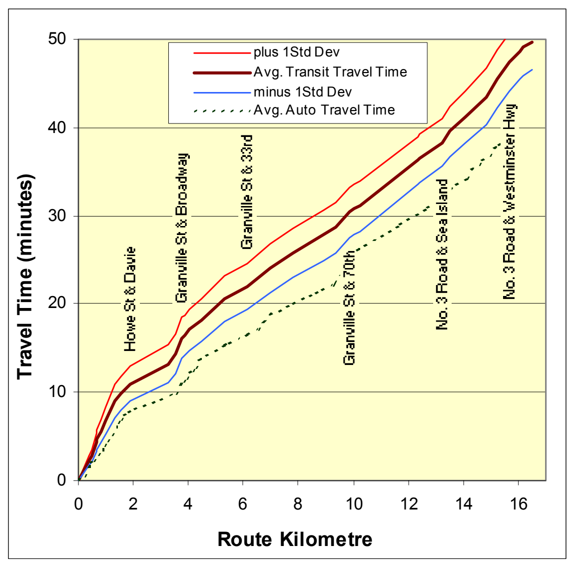
During the PM peak period, much of the variability in travel times results from traffic conditions in the downtown area and approaching Broadway and Granville. This affects both transit and auto travel times.

**Exhibit 5.1.5: Travel Time Profile, Richmond Ctr. - West Hastings Street**

**AVERAGE TRAVEL TIME NB RICHMOND CENTRE TO WEST HASTINGS AM PEAK PERIOD**

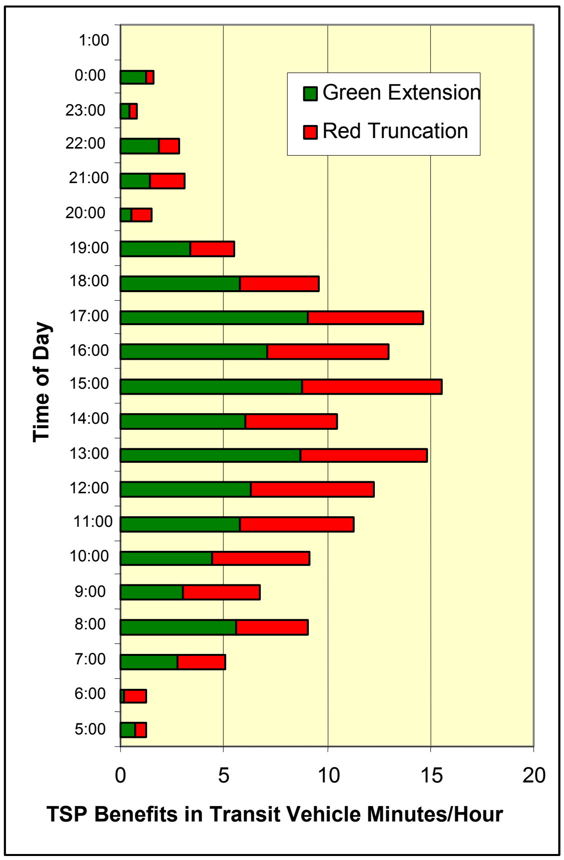
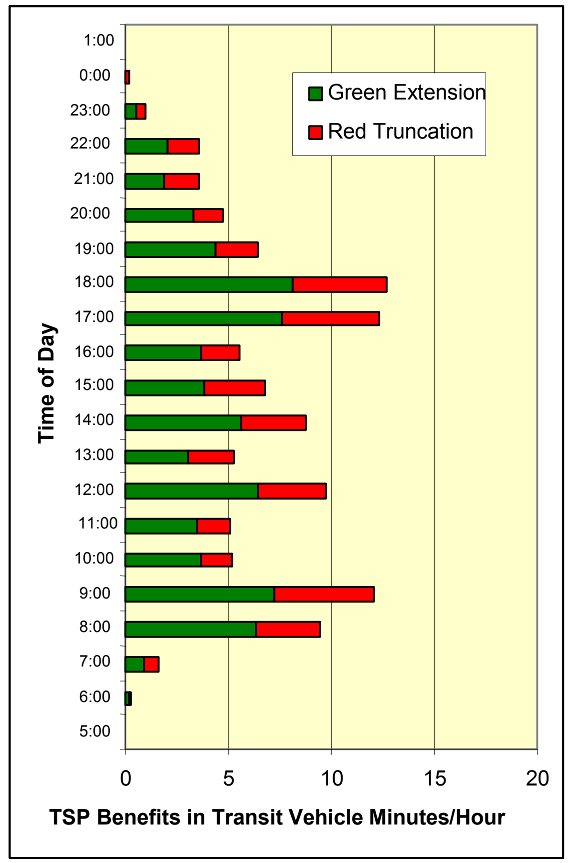



**AVERAGE TRAVEL TIME SB WEST HASTINGS TO RICHMOND CENTRE PM PEAK PERIOD**




The direct benefits of the TSP system with respect to travel time can be assessed through a review of logged TSP events. These events, which include green extensions along the corridor and red truncations on cross streets, were converted to expected time savings based on location and time specific parameters. The results of this analysis are presented in Exhibit 5.1.6 with the benefits expressed in terms of transit vehicle minutes saved per hour. Since the frequency of service on the route during the core of the day ranges from 8 to 11 vehicles per hour, the TSP benefits are in the order of 0.5 to 1.5 minutes per trip. This relatively low impact on average travel times between Richmond Centre and downtown Vancouver is not unexpected since the primary objective of the TSP system was to help maintain schedule adherence, rather than reduce travel times.

**Exhibit 5.1.6: Average Weekday TSP Benefits by Time of Day**

| NORTHBOUND RICHMOND CENTRE TO WEST HASTINGS ST. | SOUTHBOUND WEST HASTINGS ST. TO RICHMOND CENTRE |
|---|---|
|  |  |



### *5.1.2 Schedule Adherence*

In order to estimate the impact of the AVL and TSP systems on service reliability, schedule adherence data collected manually prior to the implementation of the systems were compared with data obtained from the AVL system during the week of February 8 through 14. These data were grouped by direction and time period for two sections of the route, downtown Vancouver, and the Granville Street corridor to Airport Station. The section definitions permit a statistical comparison of schedule adherence between the before and after conditions. This comparison is presented in Exhibit 5.1.7 for the downtown section and Exhibit 5.1.8 for the Granville Street section.

Within the downtown, the variability of schedule adherence has improved throughout the day in the southbound direction and during the mid-day in the northbound direction. These improvements are statistically significant based on the F-test values. The "before" data includes schedule adherence for the initial phase of implementation of the 98 B-Line as well as some of the Richmond express routes that continued to operate on Granville Street during that phase. More detailed analysis of the data indicated that the statistical relationships do not change whether or not the express routes are included.

The reduction in schedule adherence variability and the general improvement in average schedule adherence in the southbound direction is important for those users making transfers further south on the route. These improvements are also evident in the Granville Street section statistics presented in Exhibit 5.1.8.

**Exhibit 5.1.7: Schedule Adherence Statistics Downtown Vancouver Section**

| | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | **AM Peak** (6:00-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) | **AM Peak** (6:00-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) |
| **Before** | | | | | | |
| Average (minutes) | -1.2 | -0.9 | -1.3 | 3.4 | 3.9 | 4.6 |
| Standard Deviation | 2.7 | 4.5 | 2.6 | 3.6 | 3.1 | 4.4 |
| Sample Size | 31 | 118 | 59 | 59 | 127 | 81 |
| **After** | | | | | | |
| Average (minutes) | 0.0 | 1.7 | 1.6 | -0.1 | 1.1 | 0.8 |
| Standard Deviation | 2.5 | 2.6 | 2.5 | 2.1 | 2.7 | 2.6 |
| Sample Size | 322 | 623 | 409 | 330 | 720 | 441 |
| F-test value | 0.47 | 0.00 | 0.60 | 0.00 | 0.06 | 0.00 |

Note: positive values are minutes behind schedule, i.e. late arrivals

**Exhibit 5.1.8: Schedule Adherence Statistics Granville Section**

| | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | **AM Peak** (6:00-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) | **AM Peak** (6:00-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) |
| **Before** | | | | | | |
| Average (minutes) | 0.3 | 0.1 | 0.4 | 2.7 | 2.6 | 1.2 |
| Standard Deviation | 3.5 | 2.8 | 2.8 | 4.6 | 4.1 | 4.6 |
| Sample Size | 63 | 151 | 90 | 72 | 152 | 90 |
| **After** | | | | | | |
| Average (minutes) | 0.1 | 0.5 | 1.0 | 0.2 | 1.2 | 0.7 |
| Standard Deviation | 2.1 | 2.4 | 2.6 | 2.1 | 3.2 | 3.5 |
| Sample Size | 837 | 1501 | 1030 | 728 | 1580 | 1017 |
| F-test value | 0.00 | 0.02 | 0.21 | 0.00 | 0.00 | 0.00 |

Comparable statistics for the No. 3 Road section of the route are presented in Exhibit 5.1.9. These statistics are only available for the after condition. Based on the AVL data, the 98 B-Line tends to run behind schedule northbound through Richmond without significant variability. This is consistent with anecdotal information that suggests that congestion on No. 3 Road south of the busway affects transit vehicle operations, as well as high number of boardings on this section. Schedule adherence in the southbound direction is good with little change in variability relative to the Granville section.

**Exhibit 5.1.9: Schedule Adherence Statistics No. 3 Road Section**

| | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|
| | **AM Peak** (6:00-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) | **AM Peak** (6:00-9:00) | **Mid-day** (9:00-15:00) | **PM Peak** (15:00-18:00) |
| **After** | | | | | | |
| Average (minutes) | 1.2 | 2.2 | 2.0 | 0.0 | 0.6 | 1.1 |
| Standard Deviation | 1.2 | 1.8 | 1.9 | 2.1 | 3.1 | 3.6 |
| Sample Size | 987 | 1807 | 1179 | 497 | 1252 | 757 |

Average schedule reliability can also be presented graphically versus location and time as illustrated in Exhibit 5.1.10A and 5.1.10B (northbound and southbound, respectively). The 98 B-Line service appears to be systematically behind schedule northbound through Richmond, with recovery to on-time performance by Airport Station. Schedule adherence remains good northbound along Granville Street until the Broadway area is reached. There is a trend toward schedule recovery in the downtown area, although this trend weakens in the early afternoon and early evening periods.

In the southbound direction, schedule adherence is reasonably good in the downtown area, but falls behind near Broadway and at King Edward (both intersections without TSP), particularly during the afternoon and evening periods. There is some improvement in adherence between 33rd and 49th Avenues, and significant improvement after Airport Station.

It should be noted that average schedule adherence is a function of the defined schedule within the AVL system. An aggressive estimate of interpolated schedule times between timing points (Anderson Road and Airport Station for example) could lead to consistent "behind schedule" data points. Nevertheless, Exhibit 5.1.10 "red-zones" match well with the areas where congestion and other factors (e.g. stop spacing) impact route performance.

It should also be noted that the schedule adherence performance statistics may have also been impacted by ongoing refinements to the schedule by Coast Mountain Bus Company (CMBC); it is understood that CMBC made adjustments to the 98 B-line running times approximately 4 to 5 times since initial operation, including in December 2002.

**Exhibit 5.1.10A: Average Northbound Schedule Adherence**

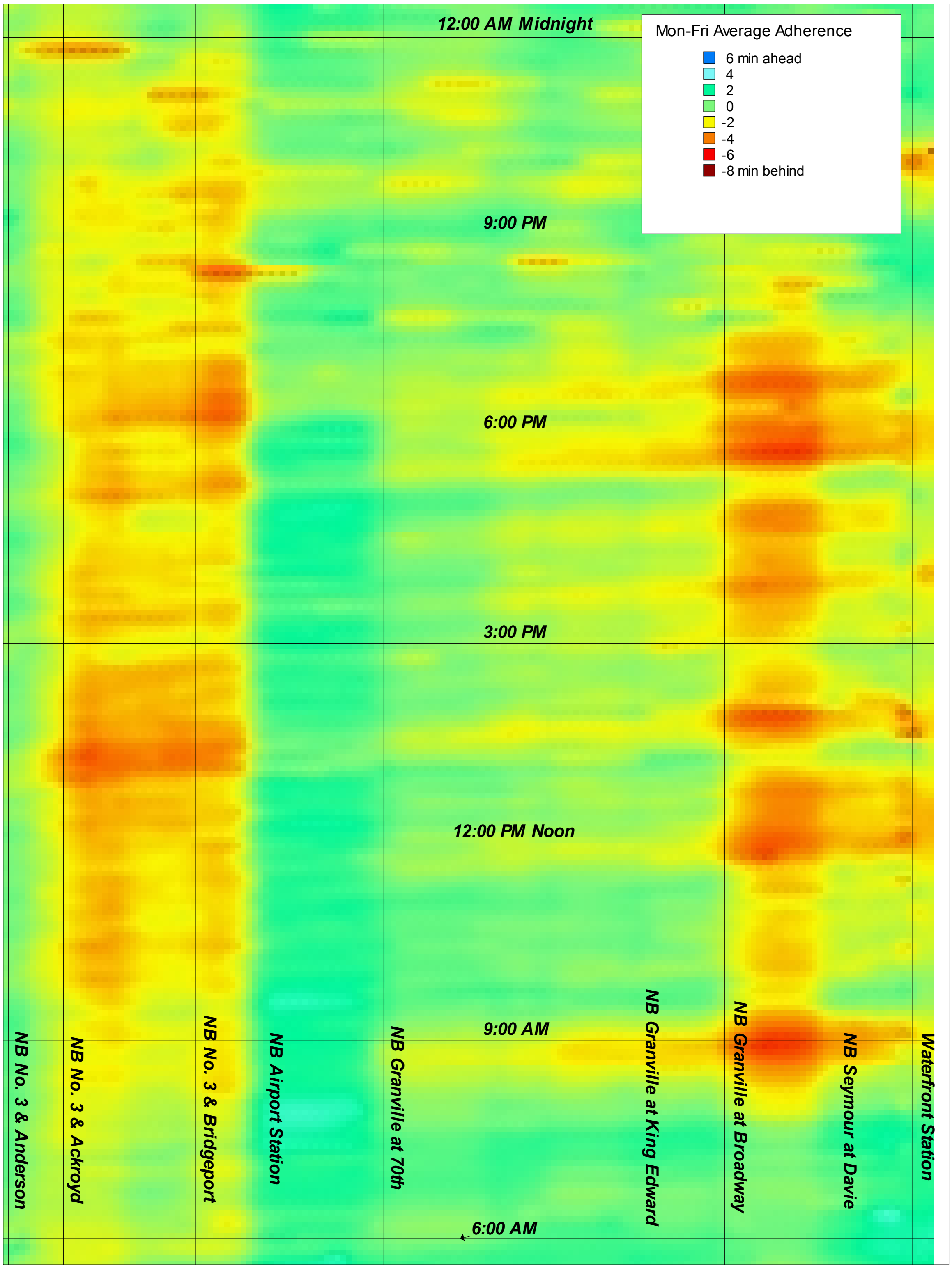
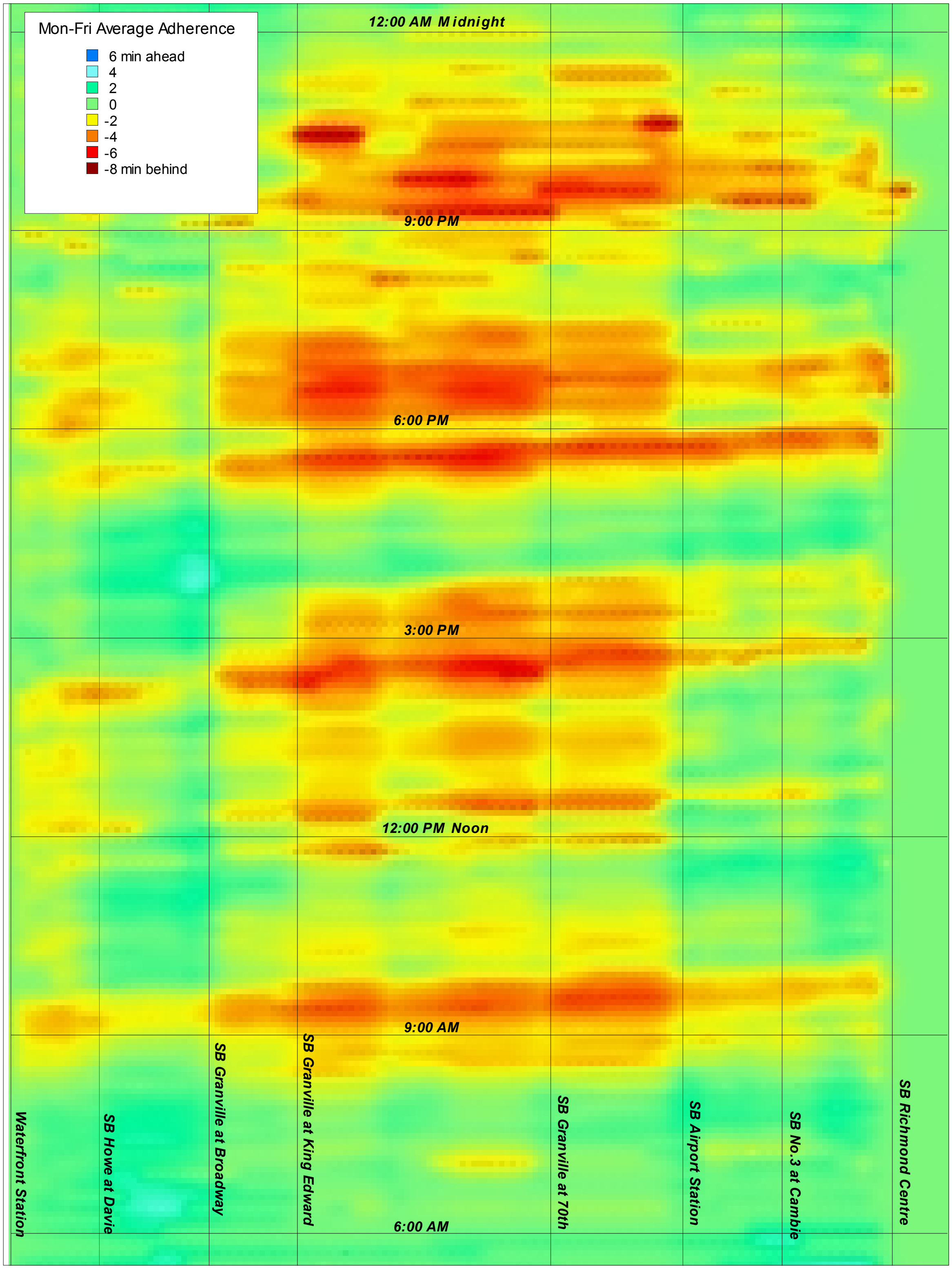


**Exhibit 5.1.10B: Average Southbound Schedule Adherence**



### *5.1.3 Customer Satisfaction*

The extent of customer satisfaction represents an important indication of user benefits. The TransLink Marketing Research Department engaged Points of View to conduct a detailed customer satisfaction survey of 98 B-Line users in February and March 2003 (representing one year since the previous survey). The survey focused on the 6 key markets for the service as follows:

The typical rider profile is young (under 45 years old), employed working commuters. Most riders are medium to heavy users of transit and only 32% are "choice riders" with access to a private vehicle. The survey was undertaken to review the key user attributes and customer satisfaction relative to:

- Previous modes of travel prior to the 98-B-Line BRT system
- Reasons for mode shift to the 98 B-Line BRT system
- Perception of travel time relative to previous modes
- Perception of 98 B-Line service improvements
- Perception of delays due to traffic signals
- Perception of the passenger information at stations

The sections that follow present the results of the customer satisfaction surveys with focus on the above mentioned attributes. Exhibit 5.1.11provides an overview of the market segments that comprised the 615 surveys undertaken, illustrating that 65% of the respondents were making longer trips, travelling between the Cities of Richmond and Vancouver.

**Exhibit 5.1.11: Market Segments Surveyed**

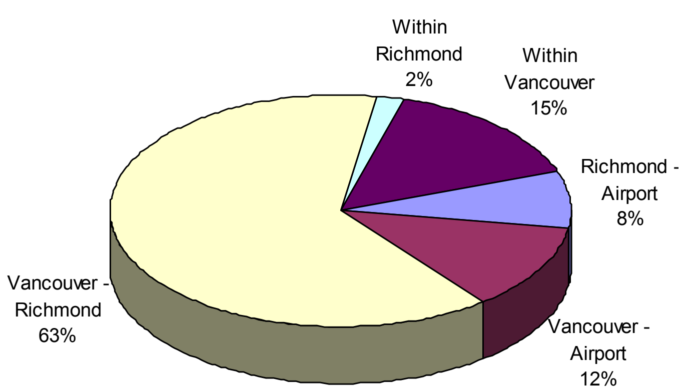



Exhibit 5.1.12 presents the respondents' previous mode of travel prior to the introduction of the 98 B-line BRT system. As illustrated, 25% of current users changed their mode of travel to using the 98 B-Line service. The results also show that 31% of the trips on the 98 B-Line are new trips, while 44% are previous transit users.

**Exhibit 5.1.12: Previous Mode of Travel**

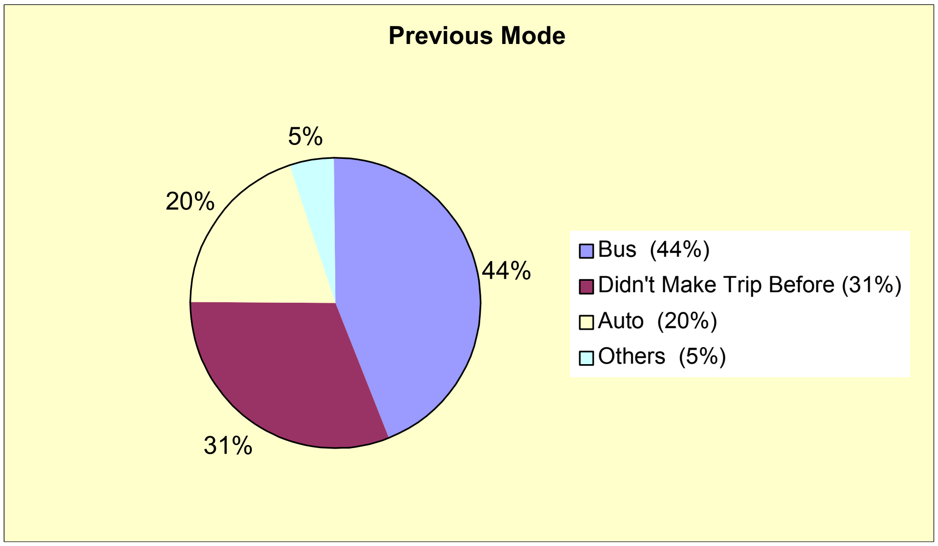



Exhibit 5.1.13 provides a breakdown of the reasons for which private automobile users changed mode to use the 98 B-Line. As illustrated in this exhibit, the primary reasons for mode change are faster service (12%), convenience (22%), and cost effective (34%), suggesting that users believe that the 98 B-line is convenient, faster, and less costly than auto travel.

**Exhibit 5.1.13: Private Auto Reasons for Switching Mode to the 98 B-Line**

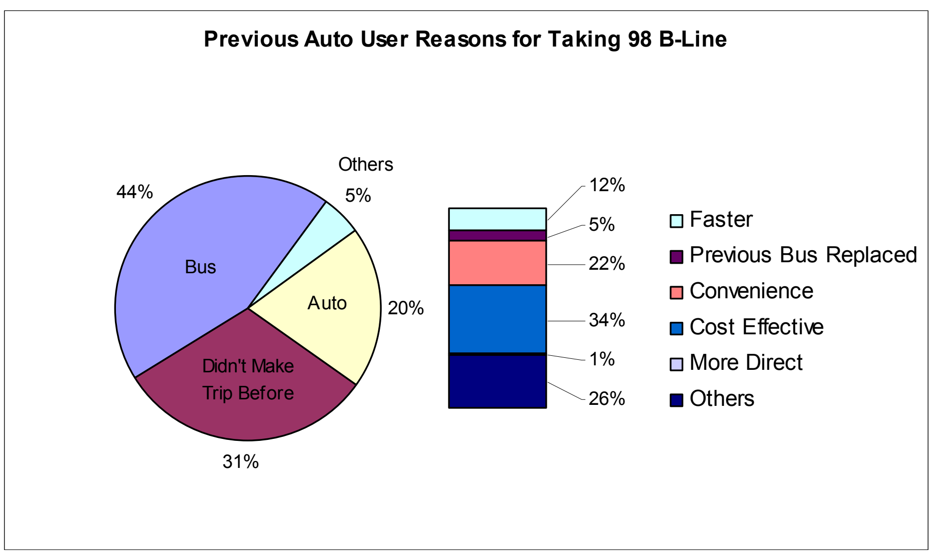
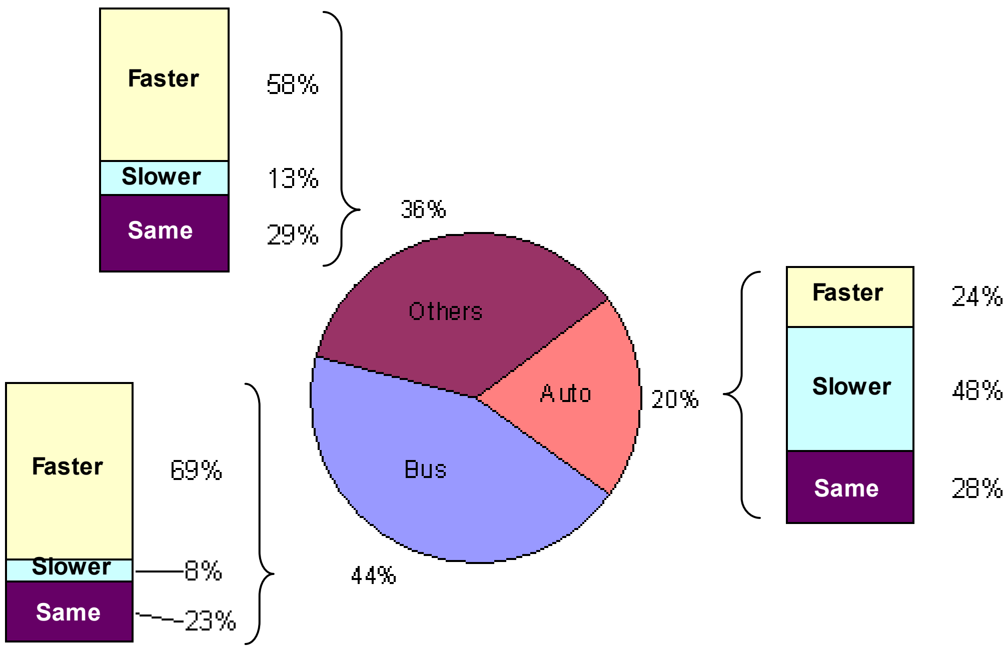


Exhibit 5.1.14 provides a breakdown of the perception of travel times relative to the previous mode of travel. As illustrated, 69% of previous transit users perceive the 98 B-Line service is faster than their previous mode. It is most interesting to note that 24% of users who used to travel by private automobile believe that the 98 B-Line service is faster, and 28% believe that it is as fast as their previous mode of travel, showing that just more than half the users believe that the 98 B-Line service is a competitive alternative to the private automobile.

**Exhibit 5.1.14: Perception of Travel Time, by Previous Mode of Travel**




In addition to the questions about previous mode of travel, customers were asked to rate the quality of the 98 B-Line service in two successive surveys in 2002 and 2003, and the results have been compared to similar questions obtained in system-wide surveys. A comparison of the rating of each of the attributes by the 98 B-Line users and by the system-wide users is presented in Exhibit 5.1.15.

Overall,

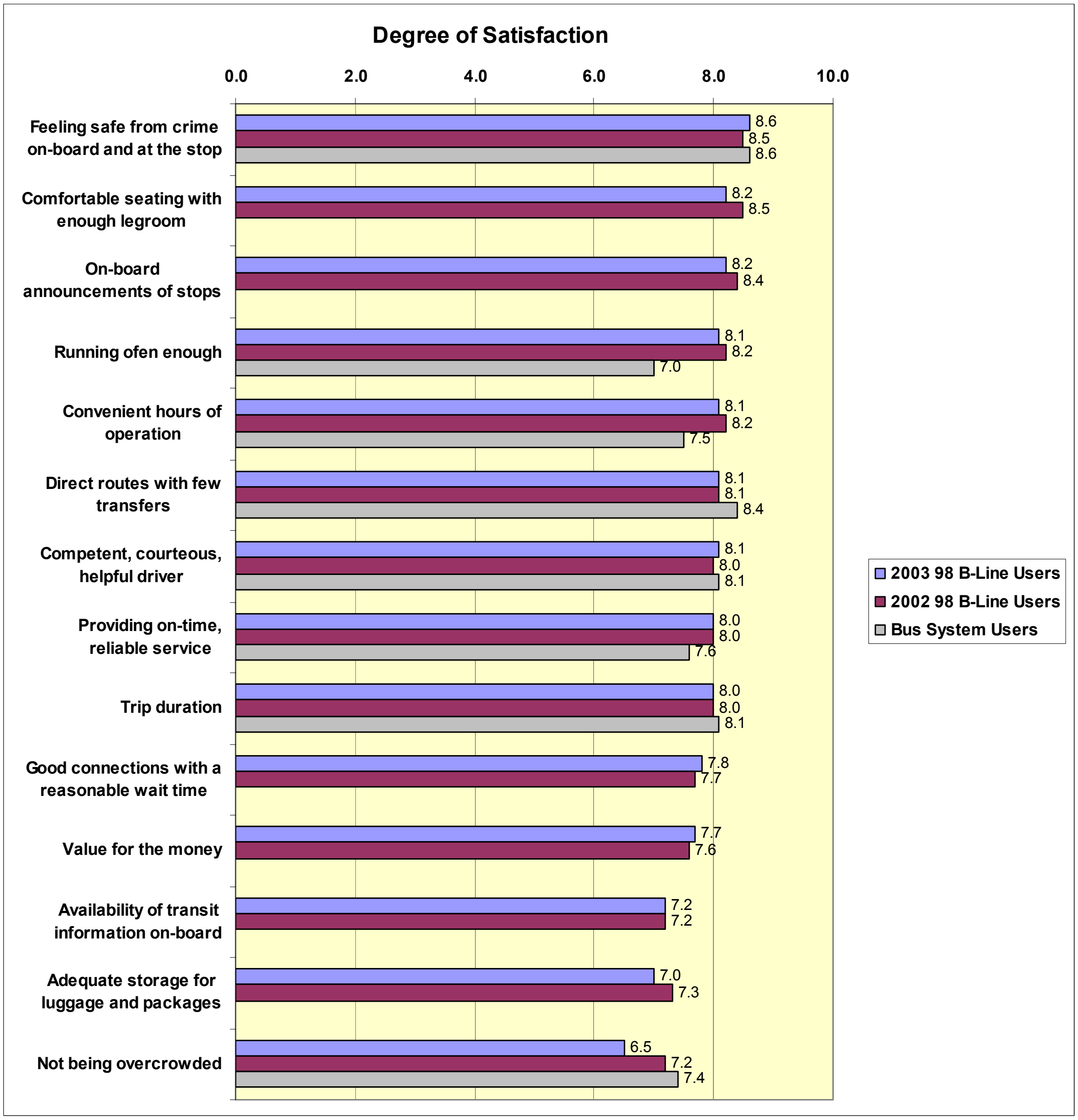
- 98B-Line users are very satisfied with the service, generally more satisfied than the system-wide users.
- However, 2003 B-Line users were less satisfied than 2002 B-Line users for service attributes relating to over-crowding, clearly a reflection of the increased usage and success in capturing ridership with the improved B-Line service.

Specifically,

- 98 B-Line users expressed strong satisfaction for the frequency of service, the hours of service and the reliability of service.

- 98 B-Line users expressed approximately the same degree of satisfaction as system-wide users for safety and courteous staff, both attributes ranking quite high by both users.
- 98 B-Line users in 2003 reported a lower satisfaction than 2002 B-Line users due to over-crowding conditions, inadequate storage for luggage and packages, comfortable seating and on-board announcements of stops.

**Exhibit 5.1.15 – Comparison of Service Attributes**




In summary, the customer surveys indicate a strong degree of satisfaction with the 98 B-Line service for most service attributes. The only area of improvement necessary appears to be the need to provide more capacity during the peak periods, through introduction of additional vehicles to meet the consistently growing travel demand.

## 5.2 EVALUATION OF OWNER/OPERATOR IMPACTS

The impact of the 98 B-Line on reduced numbers of vehicles and annual vehicle hours, as well as increased ridership, and the corresponding financial implications, are discussed in this section.

### *5.2.1 Reduction in Vehicle Travel Times*

The 98 B-Line service incorporates a number of features designed to reduce overall travel time, including:

- Less frequent stops
- Bus lanes
- Queue jump lanes

Collectively, these features result in reduced travel times. Current 98 B-Line round-trip travel times are estimated at approximately 84 minutes on average, varying throughout the day with congestion. Since there is no exactly comparable route to measure the "before" travel times, an estimate was made of the before travel time by examination of current local bus travel times (e.g. Route 8) along portions of the corridor. Through this, it was estimated that the one-way time would be approximately 50 minutes, and that the round-trip time would be approximately 100 minutes before introduction of the 98 B-Line. By comparison, the 98 B-Line travel time is estimated to be approximately 20% lower than the before travel time, which would result in 5 fewer vehicles and 20% fewer annual vehicle hours of service, compared to the "before" service.

The reduced travel times are primarily due to less frequent stops and bus lane and queue jump facilities. The benefit of traffic signal priority is to keep vehicles on schedule rather than reduce travel times. The current schedule does not reflect the reduced time that traffic signal priority measures could achieve, since the TSP is only used to keep buses on schedule. However, in discussion with representatives of the transit operator, it is estimated that the much more reliable schedule adherence as described earlier, permits lower layover time to be incorporated in the schedule and is estimated to result in potential travel time savings of 2 minutes in one direction, or 4 minutes round-trip. This reduction of 4 minutes in travel time over the entire route represents approximately 5% of the route travel time or 1 vehicle of the fleet of 24 vehicles. This vehicle and vehicle hours reduction associated with the improved on-time performance is directly attributable to the AVL and the TSP systems.

### *5.2.2 Increase in Ridership*

Ridership on the 98 B-Line was estimated to be approximately 18,000 persons per day in 2002, or 5.4 million rides per year. This ridership represents a substantial increase from 2001 estimates of approximately 14,000 persons per day, reflecting the high user satisfaction of the service, even after a protracted labour strike prior to introduction of service and a fare increase after introduction of service. The customer satisfaction survey indicated that approximately 23% of riders changed mode from auto travel to transit travel. This mode shift is very significant, and represents benefits to the operator, as well as to the users and the community. This ridership increase represents approximately 1.2 million new passengers per year. Based on an average revenue per passenger of $1 allocated to the 98 B-Line portion of a typical transit trip, this additional ridership represents additional revenue of approximately $1.2 million annually.

An additional benefit of a shift in mode from auto mode to transit mode is reduced vehicle emissions. Based on an average vehicle trip length of 8 km in this corridor and 1.2 persons per vehicle, the shift from auto to transit associated with the 98 B-Line represents a reduction of 8 million vehicle kilometres per year by private automobile. Deducting the annual bus kilometres of travel to carry this increased ridership, a conservative estimate of the net reduction in emissions attributable to the shift in mode from private automobile to public transit is:

- 1192 tonnes/year of CO2
- 0.01 tonnes/year of PM
- 4.9 tonnes/year of Nox
- 59.36 tonnes/year of CO
- 5.09 tonnes/year of HC

The improved air quality and environmental benefits realized by the shift in mode from auto to transit attributed to the much improved transit service is an important and significant contribution to the region's program to reduce greenhouse gases.

### *5.2.3 Capital and Operating Cost Savings*

The 98 B-Line results in reduction in costs to the owner for both capital expenditure for vehicles and annual vehicle operating cost.

Vehicle capital costs reduction associated with reduced travel times is estimated to be 20% of the 98 B-Line vehicle fleet, or approximately 5 vehicles or $3.2 million. This saving would be realized over the life of the vehicles of approximately 17 years.

As discussed in Section 5.2.1, the vehicle capital cost saving resulting from reduced layover time associated with the AVL and TSP systems is estimated to be approximately 1 vehicle or an additional saving of approximately $650,000 over the life of the vehicles.

Operating cost savings as a result of the reduced travel times are substantial. Based on 4,000 annual hours of operation per vehicle, a travel time saving of 20%, a fleet size of 28 vehicles and operating costs of $80 per vehicle hour, the annual operating cost saving is estimated to be approximately $1.8 million per year. This is attributed to the less frequent stops, the bus lanes and queue jumps. An additional $360,000 per year operating cost saving is attributed to the AVL and the TSP systems.

Exhibit 5.2.1 presents a summary comparison of the financial benefits and costs of the project, based on annual ridership of 5.4 million persons, i.e. the 2002 ridership levels. The costs include the capital cost of the vehicles, infrastructure improvements, land and maintenance facility, expressed in annualized terms based on 5% cost of money. Benefits include the annual operating cost savings and increased revenues, as well as travel time savings for both existing and new users, based on $10 per hour value of time.

The exhibit indicates that the annualized benefits exceed the annualized costs by approximately $3 million, and that the benefit/cost ratio is 1.3. This analysis indicates that the annual benefits to the owner/operator resulting from the higher speed, more reliable travel time provided by the 98 B-Line service is estimated to yield substantial benefits to the owner/operator in terms of fewer vehicles, fewer vehicle hours and higher transit revenue.

**Exhibit 5.2.1: Project Benefits & Costs**

| Item | Capital Cost | Life (Years) | Annualized Cost @ 5% |
|---|---|---|---|
| Costs | | | |
| Vehicles (23%) | $ 4,186,000 | 17 | $ 371,300 |
| Design/Administration | 3,600,000 | 20 | 288,900 |
| AVL/TSP | 6,200,000 | 20 | 497,500 |
| Stations | 2,600,000 | 20 | 208,600 |
| Infrastructure | 9,700,000 | 40 | 565,300 |
| Land | 5,000,000 | 100 | 251,900 |
| Maintenance Facility (Share) | 6000,000 | 40 | 349,700 |
| Operating Costs | | | 8,960,000 |
| Total | $ 37,286,000 | | $ 11,493,200 |
| | | | |
| Benefits | | | |
| Annual Operating Savings | | | 9,198,900 |
| Increased Revenues | | | 1,200,000 |
| Travel Time Savings | | | 3,982,500 |
| Total | $ 31,387,600 | | $ 14,381,000 |
| Net Benefit/Per Annum | | | 2,888,000 |
| Benefit/Cost Ratio | | | 1.3 |

Since a large portion of the capital costs are incurred, fixed costs, annual net benefits will increase each year that ridership increases.

## 5.3 General Purpose Traffic Impacts

General purpose traffic in the corridor is impacted in a number of ways, resulting from granting traffic signal priority to the BRT system. This section discusses the frequency of requesting traffic signal priority, and the estimated magnitude of the impacts.

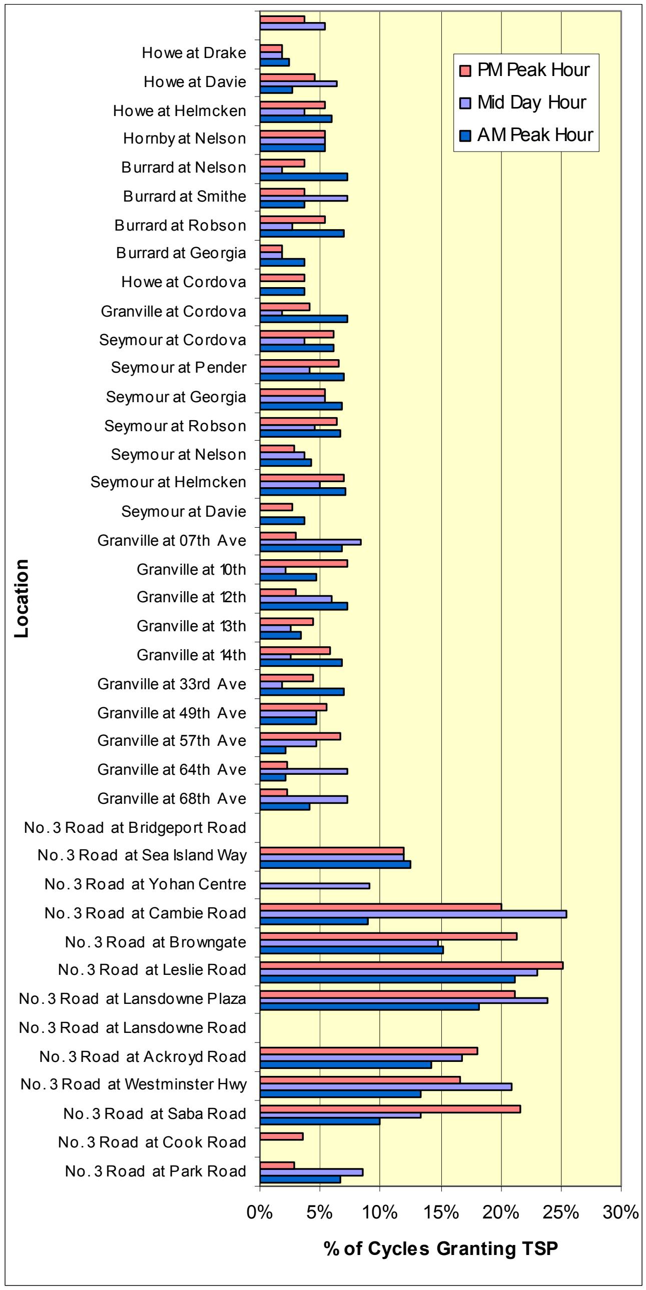
### *5.3.1 Frequency of TSP*

Traffic signal priority in the 98 B-Line is granted conditionally, that is when vehicles are 2 minutes behind schedule. The frequency at which TSP is granted to the 98 B-Line BRT vehicles provides a base measure of the potential amount of disruption the general purpose traffic experiences as a result of TSP. Using the TSP log data obtained from the traffic signal controllers in the cities of Richmond and Vancouver, the frequency of TSP grants were analyzed for the peak hour and compared against the number of cycles within the peak hour.

Exhibit 5.3.1 presents the TSP frequency data as a percentage of the number of cycles within the AM, mid-day, and PM peak hours. The following observations can be drawn from this data:

- In Vancouver, TSP is granted during approximately 5% of the number of cycles throughout the day. At the downtown intersections which operate at a cycle length of 65 seconds, TSP is granted during approximately 3 or 4 of the 55 cycles during a typical hour.
- In Richmond, the frequency of TSP comprises 15 to 25% of the number of cycles throughout the day. This higher percentage is the result of both longer cycle lengths (approximately 120 seconds) and multi-phases in the signal timing plans in Richmond, resulting in a lower proportion of green time on the main street. The longer cycle lengths also increase the travel time variability, and need for priority.

## Exhibit 5.3.1: Frequency of TSP Calls



The above results suggest that the portion of time that the City of Vancouver's traffic control signals are providing TSP comprise only a small portion of the peak hours, while the majority of the time, the traffic signal control is under normal operation. Since all of the City of Vancouver intersections that are currently TSP capable are two-phase, it can also be stated that during the 5% of time when the signals are under TSP, GP delays are experienced by cross street traffic only, while main street traffic is realizing a benefit due to more green time.

By comparison, the results suggest that in the City of Richmond, the portion of time that the traffic control signals are providing TSP comprise up to 25% of the time. Since most of the intersections here are multi-phase, it can be stated that the resultant penalty to GP vehicles is experienced by cross street traffic as well as the north/south left turning traffic. The latter group is impacted because during the red truncation strategy the north/south left turn times may also get minimized so that the traffic signal can revert back to the green phase earlier.

The TSP impacts in Vancouver are lower than in Richmond because the intersections are primarily two-phase with relatively low cycle lengths, resulting in increased probability of the transit vehicles "hitting a green light" along the Vancouver sections of the 98 B-Line route. In Richmond, TSP frequency is significantly higher because the intersections are multi-phase and operating with high cycle lengths, lowering the probability of the transit vehicles "hitting a green light".

### *5.3.2 GP Penalty Due to TSP*

In order to measure the magnitude of the impacts presented in the previous section, data associated with the duration of the green extensions and amount of red truncation have been extracted from the TSP logs and analyzed. This data is presented in two forms:

- The **average** duration of the green extension calls, and red truncation calls, within the peak hour, averaged over the five-day data collection period.
- The **cumulative** duration of green extension calls, and red truncation calls, over the peak hour, averaged over the five-day data collection period.

Exhibits 5.3.2 and 5.3.3 tabulate the average green extension and red truncation data by municipality and by time period.

**Exhibit 5.3.2: Duration of Average Peak Hour Green Extensions (in Seconds)**

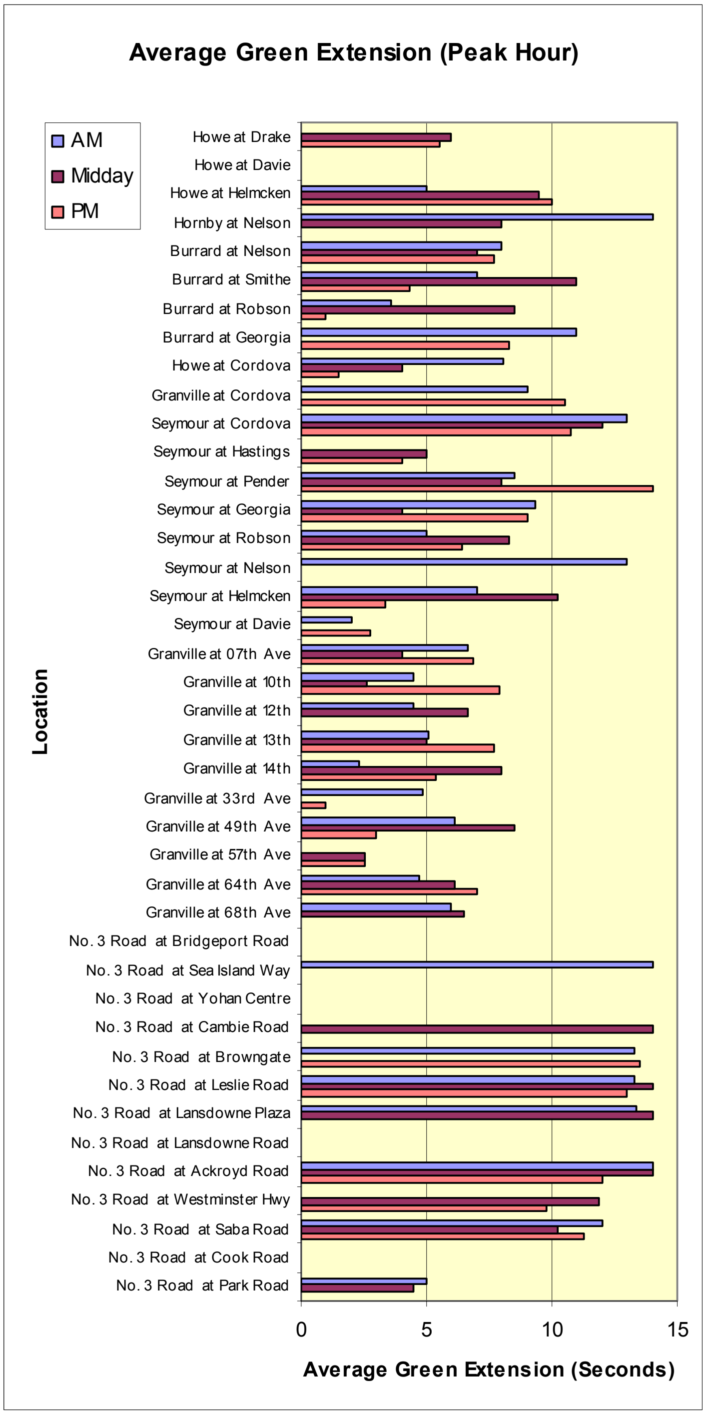
| Average Green Extension | AM | Mid day | PM |
|---|---|---|---|
| Vancouver | 6.0s | 5.4s | 5.0s |
| Richmond | 6.5s | 6.4s | 4.6s |

**Exhibit 5.3.3: Amount of Average Peak Hour Red Truncations (in Seconds)**

| Average Red Truncation | AM | Mid day | PM |
|---|---|---|---|
| Vancouver | 3.5s | 3.1s | 3.7s |
| Richmond | 7.2s | 7.9s | 8.1s |

Exhibit 5.3.4 presents the duration of average peak hour extensions in graphical format, by intersection.

### Exhibit 5.3.4: Average Duration of Peak Hour Green Extensions



As illustrated in these exhibits, the overall average green extension duration is approximately six seconds. This suggests that in general, due to the random arrival of the buses at the intersections, an average of six seconds is required between the time a 98 B-Line vehicle is detected to require priority until it has cleared the intersection.

This result shows the benefits of the dual detector (check-in / check-out) concept, showing that although a maximum green extension amount of 14 seconds is programmed in the controllers, only the amount of time actually required by the buses is used – thus helping minimize impacts to other traffic streams.

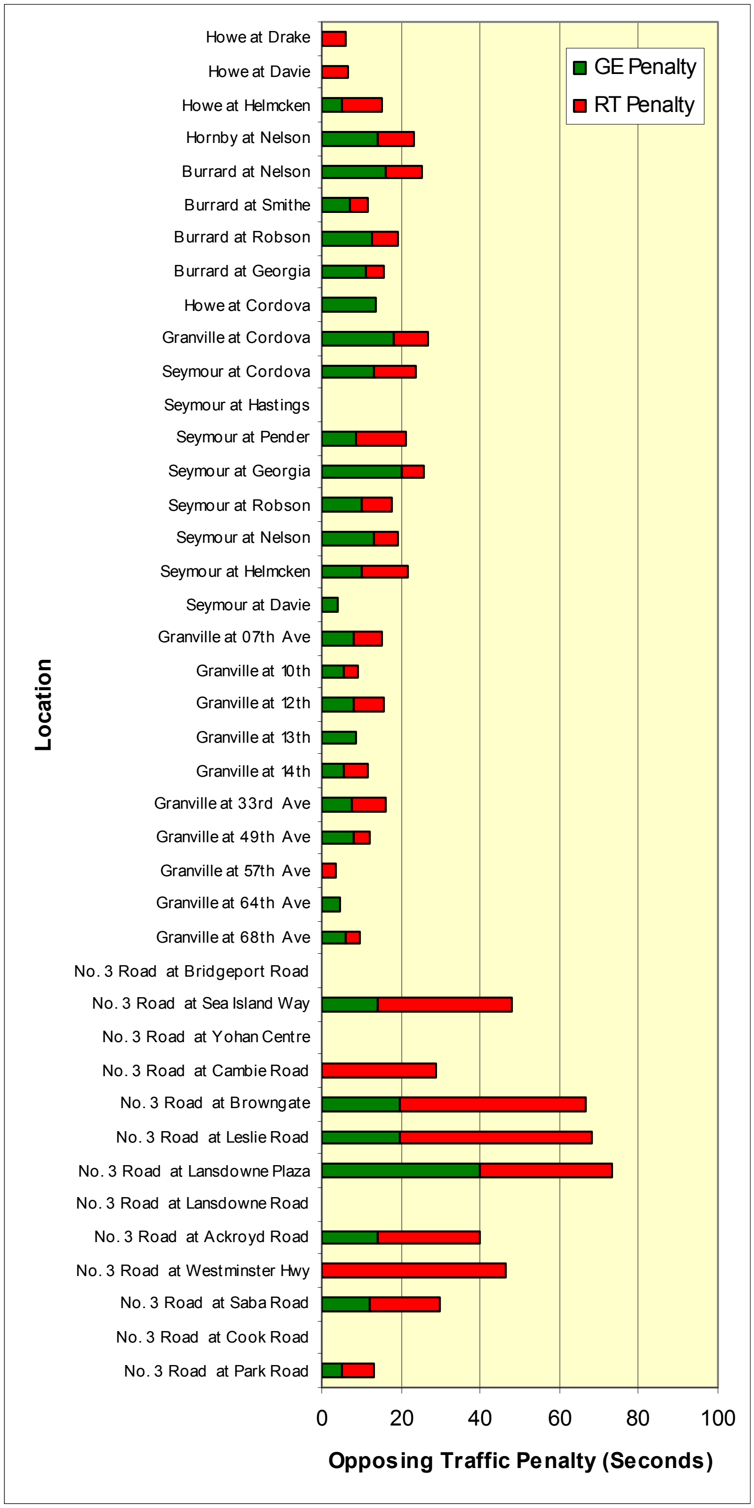
The TSP log data was analyzed further to estimate the total impacts to GP traffic in an hour. The TSP frequency data presented in the previous section has been multiplied by the duration of the TSP operations (during the peak hour) so that the penalty to GP traffic can be estimated.

The duration of the green extension calls, and the amount of cross-street time lost due to red truncation, have been accumulated to represent the total amount of delay caused by TSP during the AM, mid-day and PM peak hours. Exhibits 5.3.5 to 5.3.7 present the average weekday delay penalty experienced by GP traffic by location, during the three time periods throughout the day.

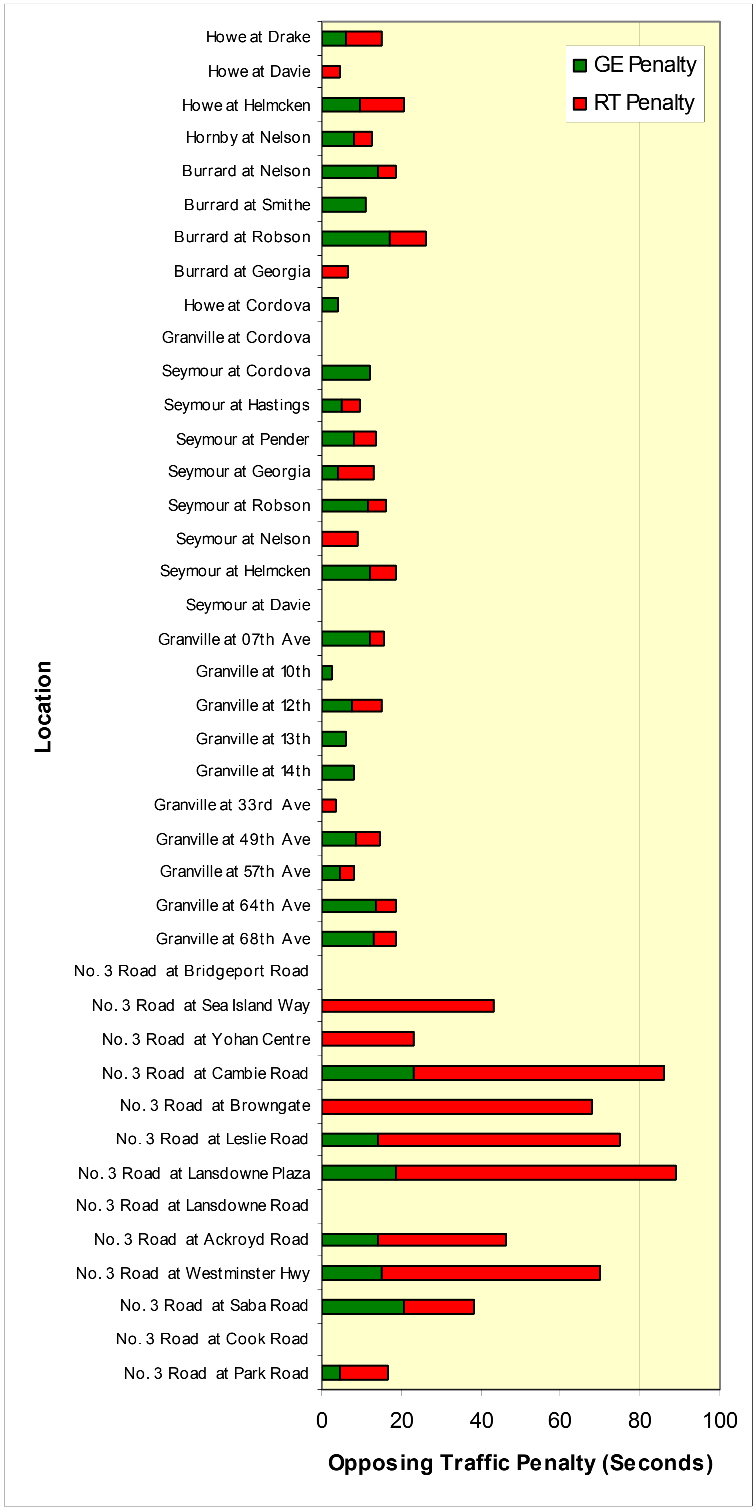
The exhibits indicate that the average sum of green extension and red truncation at each intersection is approximately 20 seconds in Vancouver and approximately 60 seconds in Richmond during one hour. Based on typical cross-street green time allocation in the two cities, the potential delay penalty to cross-street traffic in 1 hour is approximately a 1% reduction in green time in Vancouver and approximately a 6% reduction in green time in Richmond. These impacts are considered minor. Further, while the cross-street traffic may experiences a minor increase in delay, the main street traffic, which is often a higher volume, receives the green time advantage and thus realizes a benefit.

Based on this review of TSP log data, it is concluded that the frequency of TSP calls at two-phase intersections is very low, typically 5% of cycles, and higher at multi-phase intersections, that is 15 – 20%. However, due to the check in/check out concept, the actual reallocation of green time is 6 – 7 seconds per cycle, thus the overall reallocation of green time is approximately 1% in Vancouver and approximately 6% in Richmond. These impacts are deemed negligible, even at multi-phase signals where the requirement for TSP is greater. An underlying factor in these results is also the fact that buses only ask for priority when they are behind schedule – clearly demonstrating the benefits of a TSP system that is based on schedule adherence.

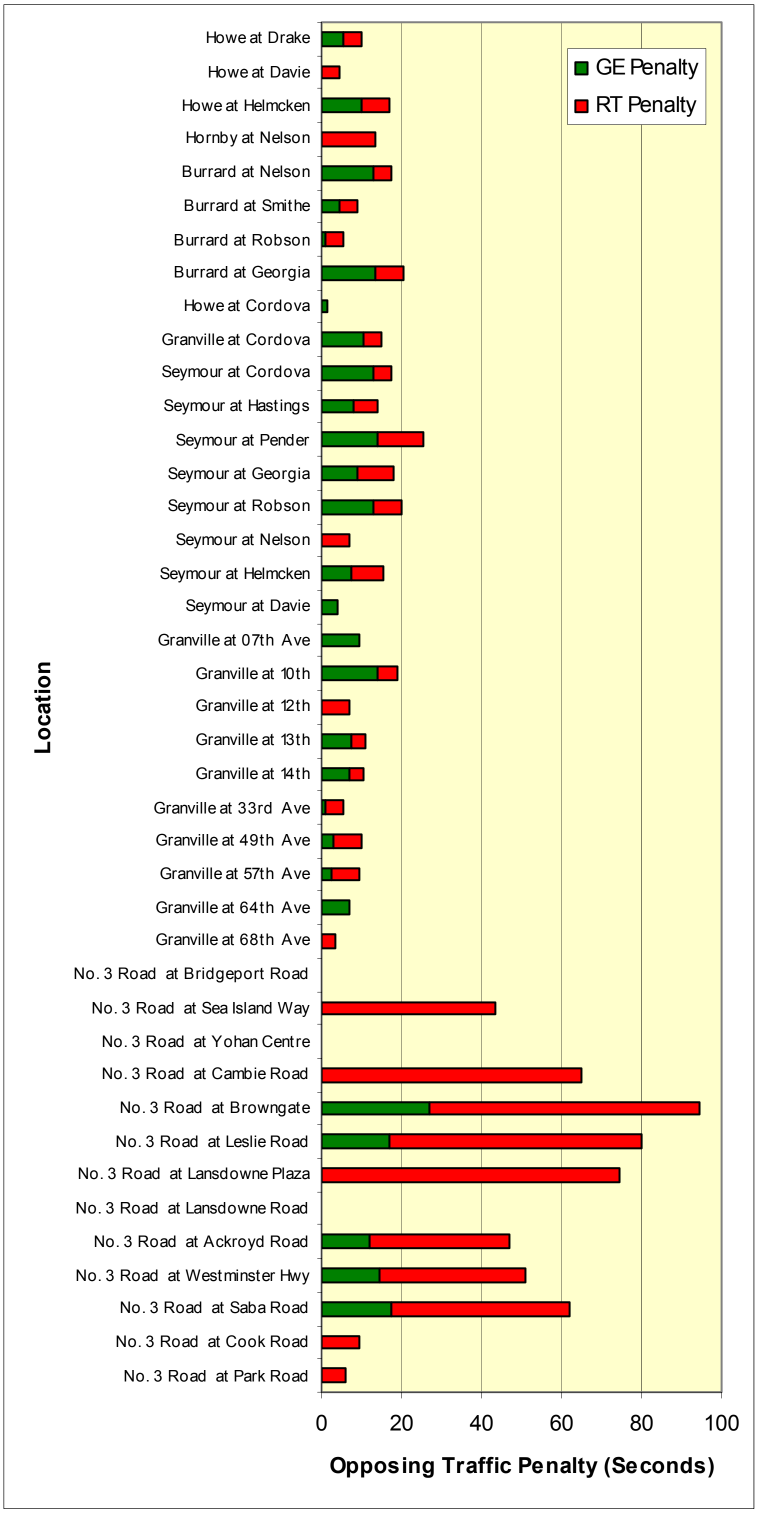
## Exhibit 5.3.5: Average Weekday – AM Peak Hour Penalty to GP Traffic



### Exhibit 5.3.6: Average Weekday – Mid-day Hour Penalty to GP Traffic



## Exhibit 5.3.7: Average Weekday – PM Peak Hour Penalty to GP Traffic



## 5.4 OPPORTUNITIES FOR ENHANCING THE 98 B-LINE

Based on the evaluation results, discussions with the owners/operators, and the customer satisfaction surveys, a number of opportunities can be considered for enhancing the 98 B-Line service. These include:

- Implementing additional traffic management improvements to favour transit operations along the corridor, such as optimizing the traffic signal timings, as well as additional turning and parking restrictions.
- Implementing enhanced/outstanding TSP measures such as the phase insert capability at the multiphase intersections.
- Examining new TSP measures such as unconditional traffic signal priority.
- Enhancing the TSP software currently operating at the traffic signals to better manage recovery after transit priority has been granted – especially for resynchronization of the traffic signals in the coordinated sections of the corridor.
- Evaluating the operational procedures of the transit management capabilities by the operator, to ensure that the central system is being used optimally.
- Adjusting (tightening) of the 98 B-Line schedule to take advantage of the AVL/TSP system impacts to travel time.
- Examining the use of variable schedule adherence thresholds by occupancy, time of day, and direction; for example, the schedule adherence threshold for full B-Lines in the PM peak direction could be one minute.
- Increasing service capacity / frequency to accommodate the high ridership.
- Adding luggage racks to accommodate patrons using the service to and from the Vancouver International Airport.
- Collecting screen-line counts across the major corridors between Richmond and Vancouver to further verify the mode shift estimates reported in this study.
- Ongoing performance monitoring and customer satisfaction surveys to ensure that service levels meet ridership / demands, and that the service is meeting passenger needs.
- Adopting necessary policies and procedures to liaise with the Cities of Vancouver and Richmond for the purpose of monitoring, managing, and refining, TSP capabilities at the signalized intersections.

# 6.0 GUIDELINES FOR APPLICATION OF BRT

One of the primary objectives of this project is to develop guidelines for application of bus rapid transit in other areas in Greater Vancouver, as well as other regions. This section draws upon the results from this project as presented earlier, as well as the project team's experience in designing the 98 B-Line and designing other BRT projects to present an overview description of where BRT should be applied, the features of the BRT system that should be provided, and the expected costs and benefits.

## 6.1 POTENTIAL BRT CORRIDORS

BRT service should be thought of as rapid transit on rubber tires, providing a higher quality service than local bus transit. As such, BRT should provide frequent, fast and generally longer distance transit service, over a period of 18 hours per day and 7 days per week. Peak period frequency should be at least 6 buses per hour (10 minute headways), and preferably 12 buses per hour (5 minute headway). Mid-day and evening frequencies should be at least 6 buses per hour (10 minute headway). Maximum frequencies of 20 vehicles per hour (3 minute headway) on routes with at-grade signalized intersections are considered the upper limit, to minimize impact on traffic signals. This range of frequencies corresponds to minimum peak hour volumes of 300 persons per hour using a 50-passenger vehicle at 6 vehicles per hour, up to 1,500 persons per hour using a 75-passenger articulated vehicle with a frequency of 20 vehicles per hour. Typical peak hour boardings for this range of service would be between 600 and 3,000 persons per hour.

For transit demand in excess of this range, consideration needs to be given to grade-separated operations to avoid excessive disruption to the traffic signal timing plans.

## 6.2 BRT TRAVEL SPEEDS

BRT travel speeds need to be higher than local bus service speeds and competitive with rail rapid transit. Typical local bus operating speeds range between 10 and 20 km per hour, in urban and suburban operations, respectively. Light rail rapid transit speeds are somewhat higher, typically 15 – 25 km per hour for at-grade LRT such as Edmonton and Calgary, and up to 40 km per hour for grade-separated rapid transit such as SkyTrain. Target BRT speeds of 25 km per hour on arterial streets are recommended. The average speed on the 98 B-Line is approximately 24 km per hour.

## 6.3 BRT DESIGN FEATURES

In order to achieve these target travel speeds, a number of physical design and ITS features need to be incorporated into the BRT system.

### Station Spacing

Station spacings should be increased to at least 2 times the local bus station spacing. Typical station spacing for BRT is 800 metres to 1,600 metres, with possibly closer spacing to as low as 400 metres in high density areas. This type of spacing is incorporated in the design of the 98 B-Line, where station spacings in the downtown Richmond and downtown Vancouver areas are

400 – 600 metres, and are as high as 1,600 metres along the lower density section on Granville Street in Vancouver.

### Queue Jump Lanes

Queue jump lanes should be provided at points of congestion, such as bridge heads, access to freeways, etc.

Queue jump lanes can also be provided at intersections where mandatory right turn lanes are available for general purpose traffic, with buses being permitted to proceed through the intersection using the right turn lane. This is a very effective, relatively low cost transit priority measure.

### Dedicated Bus Lanes

In areas of chronic congestion, particularly in the retail commercial areas, separate dedicated bus lanes should be provided in order to maintain desired travel speeds and on-time vehicle performance. These lanes may be created by restricting peak period parking, but it is preferable to have the lanes available throughout the day.

Exclusive bus lane operation can be at the curbside where there is minimal number of driveways, but should be in the median where there are numerous driveways and curbside activities. Median bus lanes also afford better fare enforcement and present a stronger rapid transit image.

One of the drawbacks in widening roadways to provide exclusive lanes for buses is the additional curb-to-curb width for pedestrian crossings, which increases the cross-street green time, at the expense of main street green time. In these situations, pedestrian activated traffic signals can be used to limit the cross-street green time, particularly in lower density corridors where pedestrian crossings are not as frequent.

### Traffic Signal Priority

Application of traffic signal priority measures will also increase transit vehicle travel speeds and improve on-time vehicle performance and travel time reliability. The simplest application of traffic signal priority is implementation of a "BRT-favourable" signal timing plan which provides a "green wave" which facilities BRT speeds and travel times, rather than general purpose vehicle speeds and travel times. This passive priority measure can provide substantial benefits with little impact on general purpose traffic. Passive signal priority measures are more applicable in locations of exclusive bus lane operations.

Active signal priority measures are more appropriate in mixed traffic operations, and are only implemented when a BRT vehicle is present.

As noted in this study, "check in/check out" type of traffic signal priority systems can improve schedule reliability substantially, thus reducing the numbers of vehicles and vehicle hours. Where travel times need to be improved further, consideration should be given to adjusting schedules to incorporate the travel time benefits of traffic signal priority, in addition to the on-time performance benefits. It was noted in this study that the frequency of TSP calls on the two-phase signal section in Vancouver is very low, which suggests that a revised schedule incorporating reduced travel times along this section should be investigated.

Another observation in this project is the much higher frequency of TSP calls on multi-phase signals. The high frequency of TSP calls at the multi-phase signals indicates a need for additional TSP priority which could be provided by incorporation of phase insert strategies, in addition to green extension and red truncation.

Traffic simulation using microsimulation models such as VISSIM are very helpful in the planning and design phase to assess impacts of transit system priority measures, and to demonstrate impacts on other traffic, usually minimal, but which are usually concerns of roadway traffic engineers. Microsimulation models can be used to examine a large number of operating situations and time periods in a very short time period, and results can be presented in video format for easy explanation and understanding of BRT operations by stakeholder groups.

#### Traveler Information

Other rapid transit-type features that should be provided in the BRT system are on-board next stop LED displays and automatic announcements, and in-station next bus arrival time LED displays. While these features do not improve travel times and on-time performance, these are features which are highly desired by users, and present an image of rapid transit-like service.

#### All Door Boardings

Similar to rail rapid transit, offline fare payment systems and all-door boarding should be provided to reduce boarding times and increase average speeds, particularly at high volume stations. However, means to enforce the fare payment policy need to be addressed.

#### Unique BRT Image

The image of BRT should be enhanced by unique design of shelters and vehicle selection. The vehicles should portray the image of rapid transit, and be differentiated in style from local bus services, in addition to providing on-board traveler information. Vehicles should also be fully wheelchair accessible and provide bicycle racks. Stations should be fully equipped with rapid transit-type services and amenities, particularly include next bus arrival time displays.

#### Public Consultation

Finally, throughout the planning and design process, the public land owners along the corridor, as well as the future users and public at large, need to be informed about the project and need to be consulted regarding design of alignment and services. Obtaining input from property owners is critical in areas where access to properties might be impacted due to construction of bus lanes or busways, and stations.

### 6.4 Cost Guidelines

BRT system costs can vary widely depending on the specific treatments of the system (bus lanes, signal priority, passenger information, etc.), as well as the location, type and complexity of construction.

The project costs presented in Section 2.4 of this report provide a basis for establishing cost guidelines for future BRT implementations. Specifically, the project costs have been used to help answer the following questions:

- What is the per kilometre cost of a BRT system incorporating a combination of dedicated lane and mixed traffic operations, as well as AVL and TSP systems?

- What is the per kilometre cost of dedicated lanes?
- What is the per bus cost of an AVL system?
- What are the per intersection costs of TSP?

Exhibit 6.4.1 provides a summary of the key cost guidelines derived from the 98 B-Line system.

**Exhibit 6.4.1: Capital Cost Guidelines**

| | |
|---|---|
| Busway<br>• Construction Cost per Lane km<br>• Land Cost per Lane km | $2.0 M<br>$1.0 M |
| Stations<br>• Cost per shelter<br>• Cost for services / platform | $60,000<br>$35,000 |
| Traffic Signal Priority<br>• Cost per intersection | $35,000 |
| Automatic Vehicle Location System<br>• Central system | $2.8 M |
| Vehicles<br>• 18 m (60 ft.) articulated vehicles | $650,000 |
| On Board Transit Management System<br>• Cost per Vehicle | $18,000 |
| Maintenance Facility<br>• Cost per vehicle (articulated) | $210,000 |
| Design and Administration | 13% |

The costs presented above are average costs for providing certain components of the BRT system, based on the particular application for the 98 B-Line. Marginal costs of expanding the 98 B-Line or applying the technology in other corridors in the Lower Mainland will be lower, since the fixed costs of the AVL system, for example, are already funded. Marginal costs of expanding the 98 B-Line or applying the technology in other corridors in the Lower Mainland may be lower for some items, since the fixed costs of some components have already been funded. On the other hand, these cost items may differ quite considerably in other corridors or in other jurisdictions due to varying site conditions.

Capital cost experience associated with implementing BRT systems in other cities is quite variable. For example, for arterial type median bus lanes, as implemented in the City of Richmond section of the 98 B-Line, the range in costs reported from other projects include US$1.5 million per mile in Curitiba, US$5 - 8 million per mile in Bogotá and Quito, and an estimated $29 million per mile in Cleveland. By comparison, the infrastructure costs associated with at-grade bus lanes for the 98 B-Line are much less costly than busways which require construction of grade-separated sections.

Operating costs for BRT service are influenced by wage rates and work rules, fuel and electricity costs, as well as operating speeds and ridership. Annually, the 98 B-Line has 71,000 service hours, which translates to an annual operating cost of approximately $5.8 million per year, at $82 per hour. Comparatively, the annual revenue of the 98 B-line service is estimated at $5.2 million, which translates to a 90% cost recovery. The annual operating versus recovery cost can also be presented on a per passenger basis, whereby the current average fare of $1.24 per passenger can be compared to a $1.34 per passenger cost.

Like the capital costs, operating costs also vary greatly from project to project. For example, Pittsburgh's East and South busway (1989) averaged $0.52 per passenger trip. Costs per trip for light rail lines in Buffalo, Pittsburgh, Portland, Sacramento, and San Diego averaged $1.31; the range was from $0.97 (San Diego) to $1.68 (Sacramento). These comparisons suggest that BRT can cost less per passenger trip and per mile than light rail transit, depending on the situation.

## 6.5 Benefits of Implementing BRT Services

Implementing bus rapid transit such as the 98 B-Line will provide benefits to the owner/operator, the user and the community at large. These benefits include:

- **Before and After Travel Times:** By achieving the higher travel speeds through the many design features described above, BRT travel times should be a minimum of 25% lower than the local bus service provided before introduction of BRT service. These benefits translate directly into a corresponding reduction in numbers of buses and annual bus hours of operation, as well as travel time savings to the users.
- **Variability in Travel Times:** This study has shown that variability in travel times is reduced substantially as a result of the design features described above, particularly the TSP systems. Reliable, on-time performance can reduce the need for layover times by at least 5%, again resulting in a direct benefit in terms of reduced vehicles and reduced vehicle hours, a benefit to the owner/operator, and more reliable service benefit to the users.
- **User and Community Benefits:** As a result of increased speeds and reduced transit travel times, this study has indicated a substantial shift from auto use to transit use as a result of the improved travel time via BRT. User surveys have indicated that more than 20% of the users are former auto users who have changed modes as a result of the much improved travel times and reliability on BRT. This shift in mode is a benefit to both users and the community as a result of less auto traffic and pollution.
- **Customer Satisfaction:** Before and after surveys of users of the service indicated strong satisfaction with the service, and its features, including vehicles, shelter design, traveler information, etc. In the Richmond area in particular, the community at large has noted the enhanced streetscape on No. 3 Road, improved traffic flow and reduced accidents.

## 6.6 The Role of BRT

The 98 B-Line is one of the most successful applications of BRT in North America, in terms of system performance, capital and operating costs, user acceptance and ridership. The application of intelligent transportation systems has played a key role in achieving this success. Transit properties throughout North America realize that, with limited capital funds available, implementation of bus rapid transit is one of the single, most cost effective way of improving transit services and ridership, at relatively low cost. The characteristics designed into the 98 B-Line service should be incorporated in the design of BRT services elsewhere, to provide rapid transit quality service at low cost.

# 7.0 PROJECT ACHIEVEMENTS

The Intelligent Transportation System (ITS) Plan for Canada: En route to Intelligent Mobility sets out the federal government's strategy for stimulating the development and deployment of these systems across Canada. The primary goals being to maximize efficiency of existing ITS infrastructure, while meeting future mobility needs more responsibly. Transport Canada's ITS Plan aims to advance the application and compatibility of ITS technologies to make Canada's multimodal transportation system integrated, safe, efficient and sustainable.

To accelerate the deployment, integration and interoperability of ITS across all modes, Transport Canada initiated the ITS Deployment and Integration Program. The 98 B-Line Bus Rapid Transit Evaluation Study was one of the projects funded under this program. This report has presented methodology and results of the evaluation, with clearly documented benefits to its users and operators. The following summarizes the key benefits and conclusions from this study in the context of the objectives identified in the ITS Plan and presented in section 1.8 of this report.

***Objective #1: Improve mobility and transportation efficiency, productivity, safety and security for passengers and freight.***

The 98 B-Line BRT has improved mobility by providing a fast and reliable rapid transit service between two of Greater Vancouver's largest municipalities. A 20% reduction in travel times has been observed. Efficiency (person throughput) of the corridor has increased significantly, due to lower travel times and travel time variability. Passenger safety and security has increased through real-time monitoring of bus locations, and enhanced / dedicated stations.

***Objective #2: Increase tourism, trade and traffic flows on north-south and east-west corridor;***

The 98 B-Line BRT contributes to increasing tourism and traffic flows along the north-south corridor between Vancouver and Richmond, by providing a connection to the Vancouver International Airport through the Airport Exchange Station in Richmond, as well as the Port of Vancouver.

***Objective #3: Improve intermodal connections, electronic commerce implementation and other strategic data exchange at transfer points and ports of entry***

The 98 B-Line BRT improves inter-modal connections through important connector stations providing links to the Airport Shuttle buses, 99 B-line along Broadway, 3 SkyTrain stations (Granville, Waterfront, and Burrard), SeaBus, and West Coast Express.

***Objective #4: Increase operational and regulatory efficiencies for system users and public agencies***

The 98 B-line BRT significantly increases operational efficiency for TransLink. The reduction in travel times and improvement in on-time performance results in reduced numbers of vehicles, reduced vehicle hours of operations and reduced capital and operating costs, all of which are benefits to TransLink and its customers. It is estimated that these improvements result in a reduction of vehicles and vehicle hours of operation of approximately 25%.

### *Objective #5: Reduce environmental impacts including air emissions and increase the use of alternative transportation modes*

The 98 B-Line BRT has resulted in a 23% mode shift from auto to transit, resulting in less vehicles on the road and thus emission reductions.

### *Objective #6: Improve traveler information and data collection for more effective policy planning and operational management*

The 98 B-line BRT has improved traveller information by providing real-time bus arrival information at stations using Dynamic Message Signs. This is facilitated by the system's AVL capabilities that tracks the location of the buses and their schedules. These capabilities also contribute significantly to effective data collection and policy planning, whereby the vehicle location data is used for logging and reporting bus performance statistics.

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In conclusion, the evaluation of the 98 B-Line BRT has demonstrated that BRT applications complemented by ITS technologies yield significant benefits in all of the areas targeted by the ITS Deployment and Integration Program. The benefits and implementation guidelines presented in this study not only help TransLink build on the success of the 98 B-Line to implement additional BRT services in the Greater Vancouver area, but also provides other regions in Canada with supporting information to implement BRT / ITS solutions – helping them meet their transportation goals and contributing to the realization of Canada's ITS Plan.