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BUS RAPID TRANSIT AND MODAL INTEGRATION

CITY OF EDMONTON
TRANSIT STRATEGY GUIDING PERSPECTIVES
BACKGROUND PAPERS



MARCH 2016

BUS RAPID TRANSIT AND MODAL INTERGRATION

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24 March 2016

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**Subject : Bus Rapid Transit and Modal Integration Transit Strategy
 Guiding Perspectives Background Technical Paper**

Dear Mr Whited,

WSP | MMM Group is pleased to present this Background Technical Paper to help inform future policy considerations as part of the City of Edmonton's Transit Strategy project that is currently underway. We hope the paper assists the City and interested stakeholders in better understanding the role Bus Rapid Transit (BRT) and modal integration could potentially play in the future Edmonton Metropolitan Region.

As noted in this Paper, the concept and implementation of BRT, as it is applied in cities and regions across North America, ranges considerably: from increased frequency on existing bus routes right through to full-fledged high-capacity rapid transit with purpose-built vehicles on major transit corridors operating in their own exclusive right of way.

This paper discusses the history of BRT, examines a number of case studies where it has been converted to Light Rail Transit (LRT), highlights the issue of integration with other modes. It also nominates three potential applications for BRT that warrant further discussion and highlights potential solutions for integrating modes at key points in the transit network, both now and in the future.

We trust this report will be useful as the City of Edmonton works with the community to develop a long-term plan for transit, and we welcome the opportunity to provide further assistance to support the City's transit strategy decision-making process as it progresses.

Yours sincerely,

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In 2014 there were at least 186 cities in the world with some type of bus priority system carrying nearly 32 million passengers per day. Bogotá's TransMilenio system (top and bottom left, front cover) stands out as one of the world's most recognisable Bus Rapid Transit (BRT) systems, however modest transit priority corridors such as Denver's 16th Street Mall (above), with specialty vehicles, frequent service, and dedicated bus lanes, can also have substantial benefits.

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EXECUTIVE SUMMARY

This guiding perspectives paper seeks to outline a number of key issues with respect to any future consideration of Bus Rapid Transit ('BRT') in the Edmonton Metropolitan Area. Given the universal trade-offs inherent in transportation planning: the allocation of finite resources, the large amounts of capital required for most transportation infrastructure and the long lead times involved with deciding upon and realising any improvements, BRT warrants serious consideration as part of any future transit network planning in Edmonton. Planning for BRT need not conflict with the existing long-term LRT Network Plan, but a number of planning considerations are critical if BRT benefits are to be understood and sufficiently evaluated.

Of particular relevance to the Edmonton context is the need to better combine any future transit network planning with a clearer understanding of the transportation and land use objectives for a particular corridor or area of the city. Unfortunately, prevailing industry standards and certifications in the BRT space – whilst informative – are found to be wanting and of little assistance in practical terms. To overcome this, three types of BRT are identified that have potential for application here in Edmonton: **Premium Bus**, **Precursor-BRT** and **Permanent BRT**.

A number of important lessons from previous attempts to forward plan for LRT by introducing BRT as a precursor are also highlighted. Many such BRT project have been shown to have been less than ideal and fraught with unexpected cost overruns. Some case studies are highlighted to show the lessons learned where this has been attempted as a way to try and avoid the mistakes of the past.

To ensure the long term success of any move towards BRT, it is suggested that a new transit planning approach along major transportation corridors in Edmonton be carried out. This would involve evaluating how each of the three types of BRT identified would operate on various Rights of Way, the likely transit markets they would be able to serve on future routes as well as the likely service delivery impacts on the existing the **focal point transfer** or **pulse model** used for scheduling buses in Edmonton. As a general rule, the more BRT contemplated, the greater the impact on existing bus services is likely to be, particularly if dedicated rights of way are contemplated.

Concerning the question of modal integration, it is found that many of the prerequisites already exist, however there is still further work to be done. By adopting a **staged modal integration approach**, and accompanying this with appropriate network planning that incorporates BRT and LRT service characteristics along identified trunk corridors, it is argued that this approach would help to better define any potential future role BRT could play in the City: both vis-à-vis existing modes and particularly if the precursor-BRT option presented here is a concept that the City considers worthy of full Business Case evaluation.

Finally, recent data and research is presented to highlight the performance of BRT in a number of contexts similar to Edmonton and also to assist with understanding where the likely trade-off between capital and operational costs lie and what has been able to be achieved with BRT in these cities. These lessons are designed to assist the City in helping to determine which transit mode might be more appropriate in which context.

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BUS RAPID TRANSIT SYSTEMS, HSU (2013)**

1

THE ROLE OF TRANSIT IN THE EDMONTON METROPOLITAN REGION: PAST, PRESENT AND FUTURE

1.1 INTRODUCTION

Edmonton, the Capital City of Alberta, is Canada's fifth largest city. The area on which the City is founded was originally part of an important Aboriginal trade route and *pehonan*, an indigenous waiting place; today the City sits at the centre of the fifth largest metropolitan region in the country in terms of population. With a regional population of some 1.36 million people in over 20 urban and 7 rural municipalities spread over a total area of some 9,246km² (Statistics Canada 2016), both the City of Edmonton and the wider Capital Region are home to substantial industrial and commercial activity.

The regional economy is notable for the substantial daily flows of goods and people over significant distances. The combination of a dispersed population base and a large geographic area makes the setting of contemporary transportation policy a delicate balancing act between prioritising scarce financial resources and ensuring that transportation system costs are distributed equitably amongst users and governments.

This paper concerns itself with a number of fundamental questions concerning **Bus Rapid Transit**, commonly known as '**BRT**'. BRT is a popular and growing form **rapid transit**, which – as will be highlighted here – can be defined and classified in a variety of ways.

Unlike many of the other forms of rapid transit that operate on exclusive rights of way (ROW), the identification of operational and conceptual distinctions between individual instances of BRT are not always as clear cut as first thought. This has implications for evaluating the relative merits of BRT vis-à-vis other transit modes. Whilst a number of informal BRT standards exist, the lack of a common definition sometimes leads to some conjecture amongst practitioners concerning what constitutes BRT, what it can and cannot achieve, and whether it is suited to a narrow set of circumstances or has application in a wide range of contexts. The assessment of these relative benefits is even less clear when BRT is compared directly against its rail-based cousin '**Light Rail Transit**' or '**LRT**'. This debate is robust and ongoing and has been characterised as 'often controversial' (Hsu 2012) and 'sensationalized' (Freemark 2011).

What is clear from the ongoing discussion is that BRT can offer a number of distinct advantages over conventional road-based transit solutions if implemented with due care and sufficient regard for local transportation policy priorities. The performance and policy merits of BRT have been found to be substantial (Tirachini, Hensher et al. 2010, Deng and Nelson 2011, Cervero 2013, Deng 2013, Currie and Delbosc 2014). These include, but are not necessarily limited to: reduced reliance on private transportation modes (Newman and Kenworthy 1999), increases in transit ridership (Currie and Delbosc 2014), reduced environmental impact in terms of lower greenhouse gas emissions (GHG) (Millard-Ball 2008) and enhanced spatial efficiency of road space (Xu and Zheng 2011).

1.2 THE EVOLVING ROLE OF TRANSIT AS AN EFFECTIVE PEOPLE MOVER

Cities throughout North America and globally have invested in transit to improve local and regional mobility. By the mid-twentieth century, as private car travel and ownership soared, most cities in the Americas had divested themselves of their legacy streetcar systems – Toronto, Philadelphia, Boston, Pittsburgh, and San Francisco were notable exceptions – and only a few cities had subways and commuter rail systems.

From the 1950s through the 1980s, Toronto, Vancouver, several American cities, and many Latin American and global cities, invested in new metro systems, often replacing surface streetcars. As metro costs soared and smaller cities became interested in improved transit infrastructure, the concept of light rail was introduced as a lower cost alternative or more politically acceptable alternative to LRT

This was particularly apparent in the United States where federal funding for a range of transit initiatives was made available through its Small Starts program. This led to what have some have described as a 'renaissance in transit' (Thompson 2003). Other US cities chose instead to access these funds to embrace BRT including Aspen and Ft. Collins in Colorado; Hartford, Connecticut; Albuquerque, New Mexico; Eugene, Oregon; Snohomish County, Washington, and San Antonio, Texas. Over time and with improving design standards and technologies, an evidence base from which to evaluate the merits of each of these transit modes has developed.

1.3 HISTORICAL MASS TRANSIT TRENDS IN EDMONTON AND OUTLOOK

In the earlier part of the twentieth century, Edmonton played host to an elaborate network of Streetcars (1908-1951) and Trolley Buses (1939-2009). In 1935 during the height of the Streetcar ascendancy, the Edmonton Transit System recorded some 13.2 million riders (City of Edmonton 2016). However whilst the post war era and the discovery of oil in Leduc in 1947 brought significant increases in population (from 150,000 in 1950 to 500,000 in 1970), this discovery was also accompanied by significant increases in vehicle ownership and private vehicle travel, leading to sharp decreases in transit use, as occurred in many other cities of the world (Thompson 2003)¹. The rise of the private automobile in this time has been well documented (Newman and Kenworthy 1999, Mees 2000, Stone 2008, Mees 2010).

Since the late 1970s one of the defining characteristics of Edmonton's transportation system and land use has been its Light Rail Transit system, or 'LRT'. Opened in time for the XI Commonwealth Games in 1978 and a first of its kind in North America, the current LRT System follows most of the technical specifications of many U-Bahn systems that can be found in many German cities. Up until recently it was operated primarily as a suburban-based service with larger distances (>1km) between stops. The system has been expanded several times since its opening, with the last extension to NAIT opening in mid 2015.

In 2015 the Edmonton Transit System consisted of some 207 bus lines, 7369 stops and 973 buses, two LRT lines (Capital and Metro lines) and the Disabled Adult Transit Service (DATS), a paratransit service for special needs persons.

¹ It is understood that the City archive and Edmonton Radial Railway Society have historical records of Street Car schedules and ridership statistics.



Figure 1 –Long Term LRT Network Plan

1.3.1 CURRENT TRANSIT SYSTEM EXPANSION PLANS AND PRIORITIES

Commencing in 2016, a new south-eastern LRT line, the Valley Line, is due to commence construction. Operated as Public Private Partnership, this new Line will connect the Downtown to Mill Woods community by passenger rail for the first time. This line forms part of the current long-term LRT Network Plan developed in 2009 (cf. Figure 1). This long term Master Plan foresees the expansion of a radial LRT network between now and 2047 based on two separate and distinctly different LRT systems: the existing suburban high-floor LRT system and a new 'urban style' low-floor LRT. Future extensions contemplated beyond the existing LRT Network Plan include connections to important regional destinations such as St Albert, Sherwood Park and the Edmonton International Airport. In the context of a fully-built future LRT network, it should be noted that these two systems are not interconnected in an operational sense; they use different vehicles (high floor versus low floor LRT).

It is important to recognise that completing the full LRT system as defined in the LRT Network Plan is a long-term strategy that will require significant funding and operating partnerships with other municipalities, as well as funding support from the provincial and federal governments. The City is currently prioritizing LRT segments for implementation according to a variety of cost, ridership, benefit, and effectiveness measures to guide the City of Edmonton's transit investment priorities and give effect to the City's long-term Transportation Master Plan *The Way We Move*. Where the outcome of prioritization means that individual corridors or segments may be deferred for construction until a later date, there may be opportunities for BRT, both as a way to build ridership for the system and to act as an interim rapid transit solution. This paper is primarily concerned with highlighting relevant issues for future consideration should the City decide to further investigate BRT as a potential option.

2 BRT ESSENTIALS

2.1 THE CONCEPT OF RAPID TRANSIT

As its name implies, BRT is concerned with ‘rapid transit’, which generally carries the connotation of a transit service that is ‘fast and frequent’. Whilst it has been suggested previously that the rapid transit term only refers to ‘rail modes’ (APTA 1994), nowadays the concept has since been expanded to encompass express buses. Vuchic (2007) suggests that *‘[the] term “rapid transit” is very popular, some cities use it for their transit systems, although they consist of buses or LRT only. Technically speaking, the bus rapid transit (BRT) mode is semirapid, rather than rapid transit.’* As discussed further in Section 2.6, Ottawa and Pittsburgh were amongst the first North American cities to adopt a system-wide, bus-based approach to the rapid transit concept.

2.2 BRT DEFINITIONS

As noted in the Introduction, given the wide range of BRT systems in existence today, a wide range of interpretations are possible for BRT.

2.2.1 TECHNICAL DEFINITION

The Institute for Transportation and Development Policy (ITDP) is a policy institute that *‘works with cities worldwide to bring about transport solutions that cut greenhouse gas emissions, reduce poverty, and improve the quality of urban life’* (ITDP 2016). It provides one of the most detailed definitions for BRT service and infrastructure. Its **‘BRT Standard’** is defined as follows:

“Bus Rapid Transit (BRT) is a high-quality bus-based transit system that delivers fast, comfortable, and cost-effective services at metro-level capacities. It does this through the provision of dedicated lanes, with busways and iconic stations typically aligned to the center of the road, off-board fare collection, and fast and frequent operations.

Because BRT contains features similar to a light rail or metro system, it is much more reliable, convenient and faster than regular bus services. With the right features, BRT is able to avoid the causes of delay that typically slow regular bus services, like being stuck in traffic and queuing to pay on board.” (ITDP 2014)

The ITDP claims that in the absence of a common definition for BRT, *‘modest improvements to standard bus service are often inaccurately labeled as BRT’*. The stated purpose of the standard is to ensure *‘BRT systems more uniformly deliver world-class passenger experiences, significant economic benefits, and positive environmental impacts’* (ITDP 2014). The ITDP chooses to use a three tier certification for BRT systems around the world: bronze, silver and gold standards.

Whilst it is laudable that the ITDP strives to see improvements in industry benchmarks and standards and wishes to protect what it calls the ‘BRT brand’, it is equally important to acknowledge most existing BRT systems were constructed prior to the standard being proclaimed. In addition to this, the standard does not appear to consider the eventuality for upgrading BRT to LRT.

The well-known Ottawa Transitway system and similar busways in Pittsburgh, Miami, and in Latin American cities that are precursors to this modern concept of BRT were conceived as ‘busways’ or

'transitways' but have since been identified as belonging to the BRT family. In the case of Ottawa, BRT is currently being converted to LRT (cf. Section 3.2.1)

2.2.2 SIMPLIFIED DEFINITION

Hsu (2012) offers a simplified definition of BRT that can readily understood and tailored to context:

'BRT uses conventional bus vehicles, restricted lanes and signal prioritization to provide a rail-like service'.

2.3 BRT SYSTEM COMPONENTS

This advantage of a simplified definition is that it encompasses the three main elements of any transit system, as defined by Vuchic (2007):

1. Right-of-way (ROW) category
2. System technology
3. Type of service

Taken together, these three elements provide a useful foundation for framing and evaluating the relative merits of BRT as a concept and its potential application in Edmonton. The choice of ROW tends to be the most critical and most contested element for the purposes of evaluating the relative benefits of BRT.

2.4 TYPES OF TRANSIT MODES

In the transportation context, a Right of Way (ROW) is generally concerned with a legal right to move along a certain specific route, space or area. Transit ROWs can be classified into one of the three categories as shown in Figure 2, which shows the interrelationship between ROW, technology and transit type.

<i>ROW</i> \ <i>Technology</i>	<i>Highway Driver-Steered</i>	<i>Rubber-Tired Guided, Partially Guided</i>	<i>Rail</i>	<i>Specialized</i>
C	<i>Paratransit Shuttle bus Regular bus (on street)</i>	<i>Trolleybus</i>	<i>Streetcar / tramway Cable car</i>	<i>Ferryboat Hydrofoil</i>
B	<i>Bus rapid transit (BRT)</i>	<i>Guided bus</i>	<i>Light rail transit (LRT)</i>	<i>(Cog railway)</i>
A	<i>Bus on busway only^b</i>	<i>Rubber-tired metro Rubber-tired monorail Automated guided transit (AGT) PRT^b</i>	<i>Light rail rapid transit Rail rapid transit / metro Regional / commuter rail Monorail Schwebbahn</i>	<i>Cog railway Funicular Aerial tramway</i>

^a Modes extensively used are shown in italic type.

^b Modes that are not in operation.

Figure 2 - Classification of urban transportation modes by ROW category and technology

The classifications in Figure 2 support the notion that BRT and LRT are similar insofar that both modes tend to fall into either the ROW A and B classification.

2.5 BRT SERVICE CHARACTERISTICS

As noted by Litman (2015) common BRT service characteristics include:

- Grade-separated right-of-way, including busways (for bus use only, also called O-bahn or Quickways)
- HOV lanes for buses, vanpools and carpools,
- Transit Signal Priority (TSP) measures. TSP involves the use of technology to increase reliability and reduce wait time at intersection for transit. Some systems use guideways which automatically steer the bus on portions of the route.²
- Frequent, high-capacity service that results in passenger waits of less than 10-minutes during peak periods.
- High-quality vehicles that are easy to board, quiet, clean and comfortable to ride.
- Pre-paid fare collection to minimize boarding delays.
- Integrated fare systems, allowing free or discounted transfers between routes and modes.
- Convenient user information and Marketing programs.
- High quality bus Stations with Transit Oriented Development (TOD) in nearby areas.
- Modal integration, with BRT service coordinated with walking and cycling facilities, taxi services, intercity bus,
- Good connections to rail transit, and other transportation services.
- Excellent customer service.
- Improved Security for transit users and pedestrians

However, as noted in the introduction, many BRT branded bus systems lack one or more of these characteristics (cf. Figure 3 **Error! Reference source not found.**).



Bus service bus lanes open only in peak periods in Auckland, New Zealand



Specially-branded 'BRT' services that replace local routes in Albuquerque, New Mexico



BRT-branded services also operate on commuter and express buses on HOV lanes in Houston, Texas

Figure 3 - BRT system examples

² TSP is also recognised as a requisite of BRT systems particularly where traffic signals account for a great part of the total delays of transit vehicles. It has proven viable in improving transit schedule adherence and in expediting transit service (Xu and Zheng 2011)

2.6 THE EVOLUTION OF BRT

BRT can be attributed to the existence of the first dedicated bus lanes in downtown Chicago (1939) and the first busway (Shirley) in Washington, DC (1969). Pittsburgh unveiled its first busway in 1977, with Ottawa introducing the Transitway in 1983. Ottawa's intention was to introduce rapid transit running on bus-exclusive ROWs, while Pittsburgh's goal was to replace its extensive streetcar network with local and express buses. The busway concept gradually spread to other parts of the world, particularly the then-rapidly growing cities of Latin America.

The modern concept of BRT – a branded rapid transit system with upgraded stations, advanced fare collection and ITS – was developed in Curitiba, Brazil in 1974. Other notable systems include Quito's El Trole (trolleybus) BRT in 1995, and Bogota's TransMilenio in 2000 (cf. Figure 16). In 2004, the first modern Asian BRT, TransJakarta in Indonesia, opened under the same design and operational principles as systems in Latin America.

Beyond Ottawa and Pittsburgh, North American interest in bus-based rapid transit through the end of the twentieth century was limited to a few isolated projects as extensions to rail systems or experiments, including the South Miami-Dade busway and the Downtown Seattle Transit Tunnel (DSTT) (cf. section 3.2.1 and Figure 10). American interest in the Curitiba BRT system in the 1990s led to funding programs dedicated to bus-based rapid transit demonstration projects in Los Angeles (the Metro Rapid system and Orange Line), Las Vegas (MAX), and Boston (Silver Line), all of which were initiated in the early 2000s. Vancouver's 98 B-Line was an early experiment that arguably set the precedent for the modern North American context, in terms of ITS integration, branded service, median busway, and predominantly mixed traffic operations.

Although the Latin American approach to BRT can be credited with initiating North American interest in BRT, the implementation approach in North America is, in most systems, much less infrastructure-intensive than in Latin American and global systems. Among the BRT systems in North America, there has been a wide variety of implementation approaches covering all aspects of infrastructure and operations, resulting in some disagreement and debate among industry professionals as to what constitutes 'true BRT'. Some practitioners branded existing express services as BRT, whilst others considered BRT as limited stop and skip-stop services that existed before, but with more upgraded buses and shelters.



Figure 4 - El Metropolitano busway in the median in Lima, Peru

Busways in Latin America, like their North American counterparts, consisted of little more than dedicated bus lanes and basic platforms. The expressway is shown above a year before its conversion (left) to the modern concept of BRT (right) with island platforms and shelters.

2.7 COMMON EXAMPLES OF NORTH AMERICAN BRT

Many North American cities have introduced BRT simply as a branded version of limited stop bus services that already existed. In San Antonio, the Primo BRT replaced the previous 91 Skip Stop route that served the corridor. Though it was initially planned as BRT, the Primo service was ultimately implemented as a mixed-traffic limited bus service with TSP. Seattle's RapidRide services were never planned as true BRT; Rapid Ride Line E (15,800 weekday boardings in 2015) directly replaced Metro's route 358 (11,700 weekday boardings in 2011). Unlike other RapidRide routes, however, the Line E service includes peak period shoulder bus lanes along much of its length, an investment in improved speed, reliability, and over 4,000 new weekday passengers. In contrast, Salt Lake City's 3500 South MAX and Houston's 401 QuickLine were added to the existing transportation corridor without reductions in the underlying local service that previously existed.



Brisbane's busways (QLD, Australia), like those in Pittsburgh and Ottawa, provide brand identity through station infrastructure and signage, but not buses.



Salt Lake City's (UT, USA) more basic level of BRT still includes key segments of busway and a distinct brand identity on vehicles and stations.



In Eugene (OR, USA), the message that BRT is a high quality, "rail like" service is emphasized in its stations, guideway, landscaping, and public art.



In Eugene, the BRT brand identity is conveyed through a common brand identity across vehicles, signage, and infrastructure.

Figure 5 - Various BRT systems in use in USA and Australia

2.8 CAPACITY

Figures 6 and 7 demonstrate the peak load capacity of a select number of BRT corridors in terms of passengers per hour per direction and daily demand.

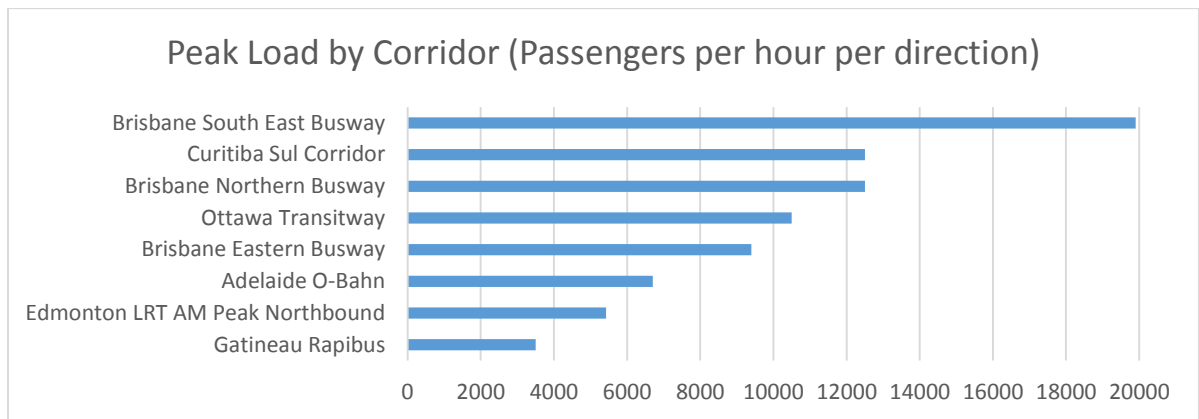


Figure 6 - Peak Load (Passengers per Hour Per Direction)³

Figure 6 data demonstrates that for data available for the Canadian context, peak load tends to vary between 3,500 and 10,500 passengers per hour per direction. This is the equivalent of about 1.5-4 well used regular bus routes. Higher peak loads are achieved in other systems.

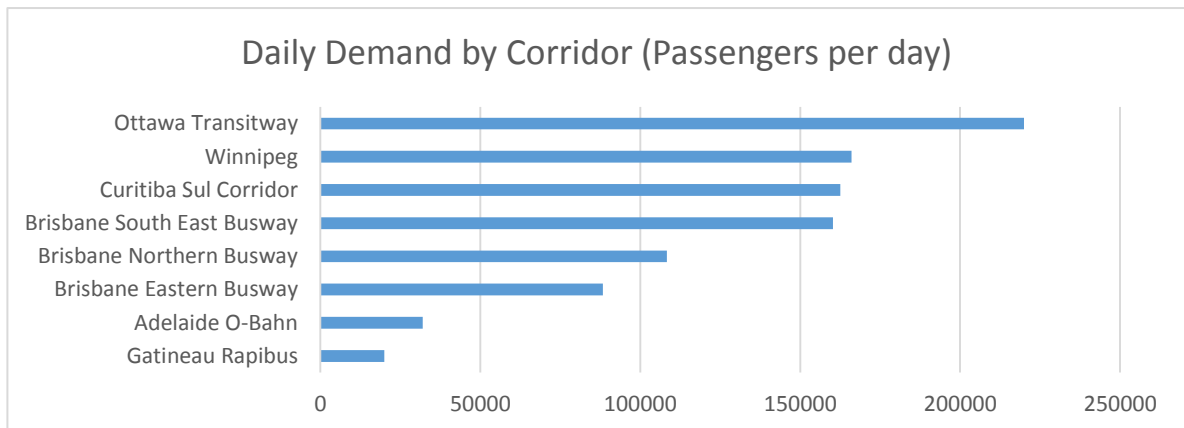


Figure 7 - Daily Demand by Corridor (Passengers Per Day)

Daily demand on high performing BRT corridors in the examples shown above tends to range anywhere from 88,000 to 220,000 passengers per day. However each of these systems has varying service characteristics. For instance, the Adelaide O-Bahn was opened in 1986 and has an operating speed of 100km/h for the majority of the 12km route. It is unique insofar that it is a guided busway located in a natural valley and an established part of the urbanised area, but its ridership catchment is generally considered limited and there is a heavy reliance on park and ride facilities to attract ridership. A new project to improve operating speeds on arterials near the city centre called the *O-Bahn City Access Project* will commence in 2016. This project involves spending AUD \$160m to construct a tunnel underneath the Botanic Gardens in order to provide a dedicated right of way into the downtown and bypass arterial road traffic.

³ Estimates used for Gatineau QC based on January 2015 service plan and informal enquiries. NB: Service restructured in 2014

3

BRT AS A POTENTIAL PRECURSOR TO LRT

3.1 INTRODUCTION

A number of cities around the world have sought to construct BRT and later convert or ‘upgrade’ this system to LRT. This chapter examines the issues inherent in this scenario and seeks to highlight the lessons learned from this experience.

3.2 PLANNING SCENARIO

The planning scenario of BRT as a precursor to LRT can be illustrated in a few select examples where conversion has actually taken place. Henry and Dobbs (2009) describe this transportation planning scenario as follows:

(a) the alignment is envisioned ultimately for LRT, but a low-capital-cost BRT-type service is undertaken until ridership demand in the given corridor grows to justify a heavier rail investment; and

(b) installation of a new LRT system or line is under way, and a BRT-type service is implemented to help build interim ridership in anticipation of the new electric rail service

3.2.1 CASE STUDIES

Henry and Dobbs identified several case studies where “a BRT-type service has functioned” in corridors that were subsequently converted to LRT, including:

Guadalajara, Mexico

LRT opened in 1989 utilizing a 5.3-km tunnel with seven stations. These stations were initially constructed for rail in 1974 but used for trolleybus service prior to conversion. The initial rail project was delayed due to a funding shortfall, and trolleybus services operated in the tunnel for fifteen years before LRT was completed (125 trolleybuses were evidently purchased used from Chicago, and replacement buses were later built locally). The transit tunnel served as the central axis of a system with two branch trolleybus lines entering from each end of the tunnel. Several surface trolleybus routes remain in operation. The current rail system includes two lines with a third line under construction. A modern BRT line with infrastructure modeled on Bogotá’s TransMilenio service has since been built, and two “rapid bus” lines operate as east and west extensions of the Line 2 LRT service.

Dallas, Texas

Henry and Dobbs note that “BRT-like” service was operated by DART on the North Central Expressway prior to opening of DART’s Red Line LRT in 1996. In this example, the “BRT-like” service operated on general lanes of a freeway, and the LRT was constructed in a parallel corridor. It is unclear however as to the exact extent to which this “BRT-like” service was different from an express bus route operating in freeway traffic.

Miami, Florida

The South Miami-Dade Busway was constructed as an extension of MetroRail service in Florida City, Miami-Dade County's southernmost municipality. The first segment of the extension to Florida City, opened on April 24, 2005, and extended the Busway 5 miles from SW 112 Ave. to SW 264 St. in Naranja. The second and final segment of the extension, which opened on December 16, 2007, now extends the Busway another 6.5 miles south from SW 264 St. to SW 344 St.; however, no rail extension has taken place since the busway was constructed. All 28 stops have been converted to light-rail style stations but their technical adaptability to LRT is less clear. Although the busway was initially considered as an interim step for the extension of rail service, there are no current plans in motion to extend the rail line.

Los Angeles, California (Wilshire Metro Rapid)

The Wilshire Boulevard Metro Rapid service is a mixed-traffic rapid bus service operating on Wilshire Boulevard. The Metro Rapid service was initiated due to high demand in the corridor and a long-term delay in extending the Purple Line subway. The subway extension is now in progress. Although the rapid bus service operates in the same corridor as the subway, the Metro Rapid was primarily conceived as a service solution; it did not support any aspect of the infrastructure investment associated with the subway.



Figure 8 – Metro Rapid 720 along peak hour bus lanes on Wilshire Boulevard, Los Angeles

Seattle, Washington (Downtown Seattle Transit Tunnel or DSTT)

The 2.2-km, five-station tunnel was initially constructed to serve dual mode (diesel-electric trolley) buses operating as downtown express routes from suburban centres and park-and-ride lots on the region's HOV and freeway network. The tunnel opened in 1990 and included embedded tracks for future conversion to LRT, which ultimately opened in 2009. Implementation of LRT in the DSTT created a number of challenges: light rail tracks were not sufficiently insulated against stray current leakage, which caused electrolysis problems, and had to be replaced. Platforms were also at the wrong height, and conversion required a change in traction power systems from trolleybus to LRT. This resulted in a closure of the DSTT for exactly 2 years while the trackway was lowered and rails replaced (with proper installation) to accommodate the Central Link LRT line. The conversion cost \$45 million (compared to the original \$466 million cost of the tunnel, not adjusted for inflation). In

in addition, Third Avenue (directly above the DSTT) was closed to general traffic during peak periods to accommodate tunnel buses that were moved to the surface as a result of the LRT project. Although some tunnel buses continue to operate, the majority of buses remain on the surface, and Third Avenue continues to be a transit-only street during peak periods.



Figure 9 - Downtown Seattle Transit Tunnel

Seattle, Washington (Interstate-90 East Link HOV Conversion)

This project is currently under construction and will result in the operation of both Central Link and East Link LRT services in the DSTT (described above), at which point all remaining tunnel buses will be relocated to surface streets in downtown Seattle. Although a multi-agency agreement established that the reconstruction of Interstate I-90 would support conversion to high capacity transit, little technical work was undertaken to support the three decade old agreement. The East Link LRT will exit the south end of the DSTT and utilize the existing I-90 reversible lanes that had been designed for high capacity transit, exiting the freeway to serve downtown Bellevue, and continuing on the SR-520 freeway to downtown Redmond. The conversion of the I-90 HOV lanes represented the major challenge to the project, both technically and politically. In addition, the project encountered significant challenges in designing a track fixation system suitable for the floating bridge; although the HOV lane geometry accommodated the LRT right-of-way, actual construction of a rail line may not have been adequately considered in the design phase of the bridge. In July 2015, Sound Transit awarded a \$20 million increase to the original \$35.8 million original contract cost (\$55.8 million total) for design of the I-90 portion of the East Link LRT. The total project budget for the overall East Link LRT is nearly \$3.7 billion for the 36.7-km project, or about \$100 million per kilometre.

Ottawa, Ontario

Ottawa's rapid transit system, the Transitway, has been in operation since 1983 and is widely considered a highly successful BRT system. The eastern and western trunks of the Transitway are currently being converted to LRT. This project also resolves the operational challenges of numerous buses operating on downtown streets through the construction of an LRT tunnel that links the two Transitways which are being converted to LRT. Interestingly, the remaining branches of the Transitway network will continue to provide BRT feeder service onto the new LRT line. The 12.5-km line includes a new 2.5-km tunnel through downtown and conversion of approximately 10 kilometres of busway to LRT service (cf. Figure 10). The project is particularly complex in that portions of the existing Transitway carry as many as 10,000 passengers per hour in the peak direction, requiring a large number of buses to serve the demand. Conversion to LRT includes a closure of Transitway serving three western stations (Tunney's Pasture, Bayview, and Pimisi) and five eastern stations (Hurdman to Blair). Bus detours during LRT construction involved a complex rerouting plan that involved construction along detour routes and significant public and political consultation. The west

detour involves two years and the widening of Scott and Albert Streets starting in 2014 to construct an expanded roadway with improved active transportation and dedicated bus lanes, followed by two years of conversion of the Transitway in 2016-2018. In contrast, the east detour was able to utilize a new lane in each direction as part of the Highway 417 expansion (2013-2015) as a replacement Transitway during the LRT conversion (2015-2018).

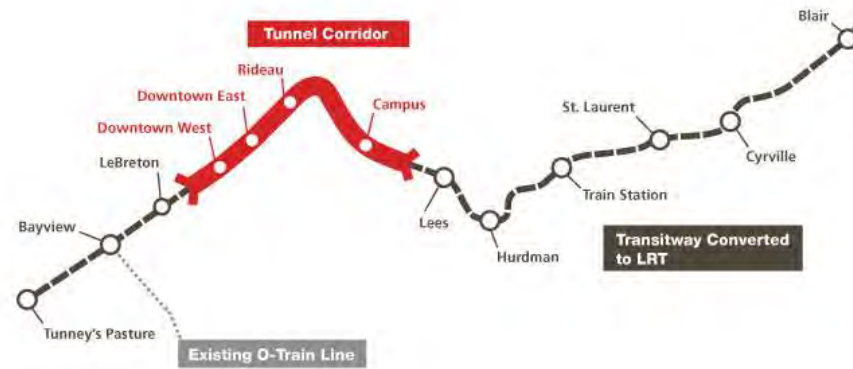


Figure 10 - Ottawa BRT/LRT Corridor

Richmond, British Columbia

The 16 kilometre 98 B-Line was a rapid bus line that served a Richmond-to-downtown Vancouver corridor along No. 3 Road and Granville Avenue. It was a limited stop service that featured prepaid fare boarding, limited stops (22 stations), TSP, and frequent service. A limited portion of the route operated on a median busway in Richmond, but most of the route operated on surface streets. The route carried over 18,000 weekday passengers by the time it closed. The service was replaced by the Canada Line rapid transit service operating underground in Vancouver primarily along Cambie Rd and as an elevated service primarily along No. 3 Road in Richmond. The 98 B-Line busway was closed for construction of the Canada Line, and the redesigned street accommodated the elevated structure of the Canada Line to the east, as well as new bicycle lanes along the route. Like the Dallas and Los Angeles examples above, the BRT (or “BRT-like”) service was replaced by rapid transit partly in a parallel roadway corridor and partly through a grade-separated alignment along the former BRT route. For purposes of this discussion, it is not considered a true precursor to the rapid transit corridor where rail rapid transit replaced BRT on the same alignment.

York Region, Ontario

The Viva “rapid bus” network is in the process of being converted to BRT with a long-term view of converting the system to LRT. Unlike Ottawa’s dedicated transitways, the York Region Viva BRT concept largely involves reconstructing urban arterial roads to include median bus lanes, known as Rapidways, and stations that are similar in geometry and design to modern urban LRT alignments. Some of these alignments have similarities with sections of the existing Capital Line along 111 St in Edmonton. Construction of the busway system is still in progress and conversion to LRT is a long-term plan. No publically available capital costs have been developed as yet. Like Los Angeles and Miami, the York Region BRT system connects to the Toronto Transit Commission (TTC) subway.

3.2.2 SUMMARY OF FINDINGS

The following are key lessons from the Case Studies outlined here (adopted from Henry and Dobbs 2009):

- The conditions that led to BRT to LRT conversions in Ottawa and Seattle are atypical of other cities that have built BRT with conversion to LRT as a long-term option, but both serve as examples of the challenges – and potential costs – of converting from bus to rail within the same corridor.
- Conversion of the short section of at-grade busway in Richmond to rapid transit involved rebuilding the overall roadway, shifting transit from an at-grade median alignment to an elevated alignment to one side of the roadway.
- The Orange Line BRT in Los Angeles and the South Miami-Dade Busway were built as alternatives to extending the metro in each city, but both cities have since opted for busway extensions rather than conversion. Likewise, Viva Rapidways were planned for conversion to rail, but this may take place in the long-term. Since both busways are at-grade and both metro systems are grade-separated, the planning implications of conversion from BRT to rail are unclear in this particular circumstance.
- Include the horizontal and vertical geometric constraints and the vehicle envelopes of both the BRT and LRT vehicles in any design considerations. LRT design constraints would generally control the design of a BRT project if future modal flexibility choices are to be accommodated.
- That initial system design, to permit a transition, is critical, and major challenges and drawbacks must be addressed and overcome. A major consideration is that the BRT facilities should not represent an obstacle to the subsequent LRT project. As noted, BRT-specific infrastructure (including stations) should ideally be designed to be very low in cost so the sunk cost for BRT is not an impediment to eventual conversion to LRT.

The following broader, general planning considerations have also been found to be warranted for BRT design that may be upgraded to LRT at a later date:

- Include the relative capacity of the two modes compared with the existing and forecasted corridor demand, the need for larger terminal stations, the potential for lower operating costs with LRT, and the capital costs associated with conversion.
- Construction activities required for conversion vary depending on whether or not the BRT system is designed and constructed to include provisions for LRT. Such activities can include modification to both the mainline and to stations. If no provisions for LRT are included in the busway design and construction, the cost of conversion can be significantly higher due to the need for more extreme modification or total reconstruction of structures and other facilities. (Parsons Brinkerhoff 2005)
- An understanding of the likely timeframe between when the BRT infrastructure is built and when the system is converted to LRT could be substantial to avoid costs associated with updated design codes and changing vehicle requirements could change (Wood, Shelton et al 2006)

3.3 BRT AS PART OF A TRANSPORTATION STRATEGY TO ‘BUILD RIDERSHIP’

This section discusses the notion that BRT can be used as a way to build the ridership base on a particular transportation corridor.

3.3.1 REAL WORLD EXAMPLES

Ottawa’s 30-year-old Transitway is one of the most well known examples of a BRT system that has increased its ridership over time to the point that conversion to LRT was required in order to improve operations and implement a ‘next generation’ solution with additional ridership capacity.

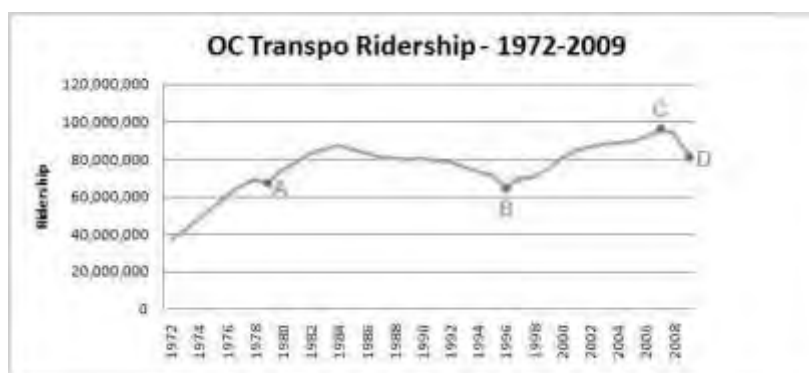


Figure 11 - OC Transpo Ridership 1972-2009⁴

Ottawa is well known for its journey to work trends that rival the Toronto and Montreal regions, both of which have substantial passenger rail services (cf. Figure 12), demonstrating the inherent appeal of rapid transit.

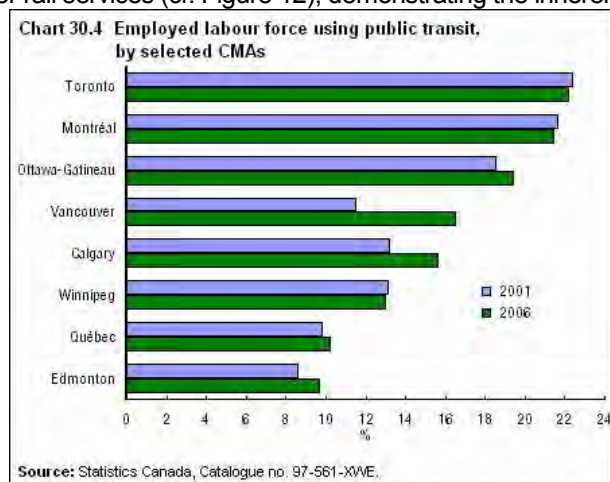


Figure 12 – Employed labour force using public transit 2001/2006

⁴ According to Raaymakers (2010), **Point A** denotes a 20-day strike in 1979, which became known as the ‘five-cent bus strike’. **Point B** marks 64.812 million rides in 1996, where ridership had declined 11 of 12 years from 1984 until that year (which also had a 21-day strike to go along with the downward trend). In the years preceding, due to the declining ridership, a comprehensive review of OC Transpo operations was undertaken to find the root causes. Part of the problem is attributed to the steep rise of fares: Cash fares were only \$0.65 in 1981, but they broke the one-dollar mark in 1985 and had climbed to \$1.50 by 1987, and \$2.00 by 1992. Fares were subsequently reduced to \$1.85 in 1996, which appears to have contributed to reversing the trend. **Point C** marks the all time high of ridership in 2007, whilst **Point D** reflects the 51-day 2008-09 winter transit strike, which brought ridership down in 2008 and especially in 2009.

The Victoria Transport Policy Institute (2015) has also noted the following with respect to dissecting the ridership growth impacts of BRT schemes in North America and the estimated portion of new Transit Users (cf. Table 1)

Table 1 - BRT Ridership Impacts

BRT SYSTEM	RIDERSHIP GROWTH	PORTION OF NEW TRANSIT USERS
Vancouver 96B	30%	23%
Las Vegas Max	35-40%	24%
Boston Silver Line	84%	NA
Los Angeles	27-42%	NA
Oakland	66%	32%

Source : Victoria Transport Policy Institute/BC Transit (unpublished research)

In the case of the Los Angeles Orange Line, VTPI research and interviews with transit operators suggest that many of the new riders were previously car drivers and one of the major benefits to emerge from BRT is a demonstrable decrease in traffic congestion, particularly on freeways (ibid).

3.3.2 CONTEMPORARY EXAMPLES FROM APPLIED TRANSPORTATION RESEARCH

Currie and Delbosc (2014) conducted analysis based on a range of Australian cities that suggest both large scale busways and the cheaper on-street BRT have characteristics which can generate good ridership performance over time. They note the principal factors influencing ridership performance are:

'high service levels, low speeds⁵, shorter stop spacing, segregated rights of way, modern accessible vehicles, lower fares, system integration and pre boarding ticketing'.

They also note that operationally, **'segregated rights of way act to improve BRT operating speeds and reliability compared to on-street BRT'** are important to build ridership (ibid).

Using a methodology that involved collecting information on 46 cities between 1974 and 2010 and conducting a comparative analysis by using a large number of disparate sources including direct contact with current operators, BRT web sites and from specialist groups engaged in BRT system planning (such as Embarq and ITDP-China) from 15 countries, Hensher and Li (2012) found a number of similar attributes contributed to higher ridership, including:

- Low fares
- Length of scale of BRT network route lengths
- Shorter interstation stop spacing
- Integration of systems with the wider transit network
- Shorter transfer distances at stations
- Pre boarding ticketing.

⁵ Currie and Delbosc note that direction of causality for 'low speeds' is unclear and hypothesize that low speeds is *'often associated with congested, inner-urban areas of high density'*

3.4 CAPITAL AND OPERATING COSTS OF BRT VERSUS LRT

Comparisons of capital and operating costs of BRT across cities with differing cost bases, time periods, project specifications and methods of recording data is not a straightforward task. Collaborative efforts such as **BRTData**, a project lead by EMBARQ, is part of the World Resources Institute (WRI) Ross Center for Sustainable Cities. The WRI's broader sustainable cities program has helped to create a data collection platform with assistance from member organisations, the International Energy Agency (IEA) and the Latin American Association of Integrated Transport Systems and BRT (SIBRT) to try and simplify data analysis for comparison purposes.

3.4.1 CAPITAL COSTS BY SYSTEM TYPE

The Transit Cooperative Research Program (TCRP), sponsored by the Federal Transit Administration in the USA, has estimated cost relativities between 6 define, hypothetical BRT development scenarios (in 2004 US dollars, cf. Table 2):

1. Grade-separated busway (14 miles) and CBD bus lanes (1 mile)
2. At-grade busway (14 miles) and CBD bus lanes (1 mile)
3. Median arterial busway (5 miles), at-grade busway (5 miles), mixed traffic (4 miles), and CBD bus lanes (1 mile)
4. Bus lanes with TSP (10 miles), mixed traffic (4 miles), and CBD bus lanes (1 mile)
5. Bus lanes without TSP (10 miles), mixed traffic (4 miles), and CBD bus lanes (1 mile)
6. TSP in mixed traffic (15 miles)

Table 2 Estimated BRT Ridership Impacts and development costs based on six scenarios

ITEM	GRADE-SEPARATED BUSWAY	AT-GRADE BUSWAY	AT-GRADE BUSWAY & MEDIAN ARTERIAL	BUS LANES (REBUILT) & TSP	BUS LANES ONLY	TSP ONLY
Existing (base) one-way travel time	94 min	94 min	94 min	94 min	94 min	94 min
BRT in-vehicle travel time	29 min	43 min	48 min	50 min	57 min	58 min
% reduction	69%	54%	49%	47%	39%	38%
Assumed BRT base ridership	10,000	10,000	20,000	8,000	8,000	8,000
Anticipated BRT ridership	17,660	15,700	33,020	11,600	10,885	10,815
% increase	77%	57%	65%	45%	36%	35%
Existing local bus ridership	20,000	20,000	20,000	16,000	16,000	16,000
Anticipated local bus ridership	10,000	10,000	-	8,490	8,490	8,000
Estimated development costs*	\$242.0 million	\$109.4 million	\$84.3 million	\$40.3 million	\$12.5 million	\$11.4 million

Source : TCRP Report 118

Based on the analysis of these 6 scenarios, TCRP researchers draw the following conclusions:

1. As BRT development costs increase, there is a consistent reduction in travel times and a growth in BRT ridership.
2. Faster travel times reduce operating costs for any given bus volume.
3. The busway scenarios, because of their exclusive right-of-way and wider station spacing, have the greatest gains in speeds and ridership, but also the greatest investment costs.
4. The lower-cost scenarios (i.e., bus lanes and TSP) have the smallest time savings and ridership gains.
5. Travel time savings appears to be the greatest contributor to BRT ridership gains, followed by the provision of special BRT features. While BRT may run at short intervals, the splitting of corridor service between BRT and local bus operations may limit computed BRT ridership gains because of the combined bus frequencies.

They also note that '*any city-specific analysis should reflect local conditions in terms of land and construction costs, population and employment growth, and land development impacts*'. (TCRP 2007).

3.4.2 CAPITAL COSTS BY CITY

By contrast, and by drawing upon real world data, EMBARQ (2013) collected BRT per kilometre capital costs from around the world to ascertain cost differentials between each of the BRT projects studied.

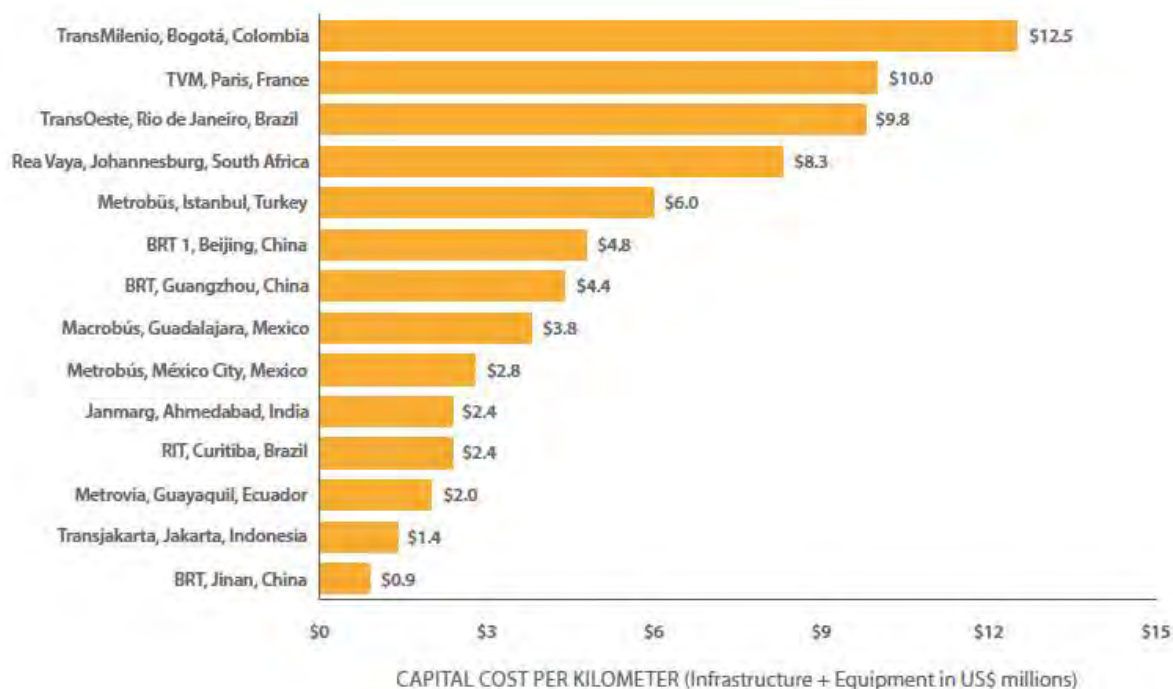


Figure 13 - Capital Cost per Kilometre of BRT

By way of general comparison, Hsu (2012) suggests that the capital costs of LRT in the North American context tend to be higher than those BRTs examined by EMBARQ and feature a wide range of variability, ranging from a low of \$10.3 million per km for the Orange Line in San Diego to a high of \$66.0 million per km for the 10.3 km LRT system in Buffalo (77% tunneling).

3.4.3 OPERATING AND LIFECYCLE COSTS

ITDP (2012) notes that locating and conducting comparisons of operating and maintenance (OM) costs across BRT systems tends to be even more difficult than capital costs. Hsu (2012) developed a methodology on a unit cost basis. The standard cost components of both BRT and LRT systems were used to avoid unnecessary complications. The unit costs allocated to the cost components of capital and operating costs in the model used were derived from historical data of existing systems.

Hsu drew the following conclusions based on the analysis undertaken⁶:

- **On a per unit distance basis**, the longer the route length, the lower the cost for both LRT and BRT systems; however, as the route length increases, the OM cost increases. With longer route length, the OM cost of the BRT is much higher than that of the LRT.
- **With respect to alignment configuration of LRT guideway or BRT running way**, the capital costs of both LRT and BRT systems will increase greatly if the system is to be elevated or put underground, especially in the case of tunneling. The capital cost of the BRT is more expensive than that of the LRT if there is a portion of elevated or tunnel alignment. The OM costs of BRT systems are more expensive than those of LRT systems. However, the OM cost will not change no matter how the alignment configuration may change.
- **With respect to ROW configuration**, the capital and OM costs of LRT and BRT operating on a non-exclusive ROW feature higher capital and OM costs than those operating on an exclusive ROW. LRT vehicles exhibit larger size vehicles and can carry more passengers than bus vehicles. With the same passenger demand volume and route length, the differences of capital or OM costs of the BRT that operating on a non-exclusive ROW and an exclusive ROW are greater than those of the LRT. The OM cost of BRT depends primarily on ROW configuration.

A summary of this analysis can be found in Appendix B.

⁶ Input Assumptions to analysis: Passenger demand volume = 3,400 pphpd; route length = 14.6 mi; number of stations and stops = 16; LRT ¼ 68 seats/vehicle, 2.8 passengers/seat; BRT ¼ 50 seats/vehicle, 0.9 passengers/seat; 1 mile = 1.609 km. costs are in year 2009 U.S. dollars.

4 INTEGRATION OF LRT WITH CONVENTIONAL BUS AND LAND USE CONSIDERATIONS

4.1 CONTEXT FOR BUS AND LRT INTEGRATION

This section is concerned with the long term modal integration of LRT with other modes, including BRT and non-motorised modes, and examines the issue of integration through the prism of sustainable development objectives, which were most recently revised at the United Nations Sustainable Development Summit in September 2015 (UN 2015).

According to the VTPI (2011) “*Sustainability emphasises the **integrated nature of human activities and the need for coordinated planning among different sectors, groups and jurisdictions**” (author emphasis). The VTPI nominates **system integration** as a planning objective that can help to achieve sustainable transportation goals, including those nominated in *The Way We Move*:*

- Transportation and Land Use Integration
- Access and Mobility
- Transportation Mode Shift
- Sustainability
- Health and Safety
- Well-maintained infrastructure
- Economic vitality

The section also focusses in part on land use due to the low density nature of Edmonton's urban form and the well documented correlation between urban density and transit use (Newman and Kenworthy 1999).

A discussion of current operational characteristics of transit and their impact on, can be found in section 5.4 ('Staged Network Integration').

4.1.1 THE NOTION THAT BRT AND LRT ARE NOT COMPLEMENTARY

In response to articles published in The Globe and Mail and The Wall Street Journal in 2011, Yonah Freemark, an urbanist and journalist from Chicago, IL and chief author of the blog thetransportpolitic.com, lamented “*the sense that BRT is inferior to rail by putting the two in contrast to one another, rather than focusing on the relative benefits of each*”. Freemark argues that there are merits in selecting any given mode, that most cities choosing rail still need additional investment in buses, and BRT and rail modes should be viewed as complementary to one another, rather than as competing alternatives (Freemark 2011).

4.2 LAND USE

Land use has been found to be a key driver of most transportation outcomes (Newman and Kenworthy 1999). Cervero and Guerra (2011) contend that higher cost transportation systems that are conducive to higher levels of urban mobility need healthy urban density to be financially sustainable. They conducted work with focus groups in Stockton, California using photo simulations and found ‘a clear disconnect between the kind of high-quality transit services that would be required to make a dent in Stockton’s modal splits and the the kinds of urban land-use and streetscape transformations that would be needed to support these radically improved transit services’.

A general preference was expressed by focus groups for the lower density streetscape. Cervero and Guerra suggest this may lie in a lack of understanding what some of the prerequisites are for high-ridership transit (i.e. dense land use). This suggests that cities wishing to see increased integration of transportation and land use in order to improve the performance of the transportation system as a whole should engage in further public education around these goals.



Figure 14 – BRT and Density Photo Simulations



Figure 15 – Bogotá TransMilenio

*Bogotá's autopistas were reconstructed to incorporate the **TransMilenio** BRT system (above, note the strict segregation of land uses and consumptive impacts on land), while city arterials were converted to include median bus lanes or as bus-only roadways (bottom, note relative impact of BRT in denser urban form).*

4.3 MODAL INTEGRATION IN AN EXPANDING CITY

The ITDP has found that transit performance and efficiency is closely tied design characteristics and level of integration with other modes (ITDP 2014).

The latest BRT research into user preferences and route choice (Raveau, Munoz et al 2016) and passenger information systems (Zurob, Allard et al 2016) leads Hidalgo et al (2016) to suggest that “a transit system will provide a higher level of service to its users if it is designed for passengers to move between trip legs as smoothly as possible, and if they understand the system's inherent complexity so as to be able to find their best possible route choice” and that this can be realised by way of an integration framework. As Edmonton's transit system is sometimes criticised for being difficult to understand (sometimes referred to as ‘transit legibility’), this underpins the need for enhanced modal integration in the future.

4.3.1 THE ROLE OF AN INTEGRATION FRAMEWORK

Hidalgo et al (2016) developed their integration framework by examining case studies from Santiago and Bogota. They draw a distinction between five key aspects of integration:

1. **Physical** *'the opportunity for exchange of passengers between different types of services and modes'*
2. **Operational** *'coordination of schedules, so passengers can transfer smoothly from one service to another'*
3. **Fare** *'allows passengers to use different services with the same payment method as well as 'allowing for more sophisticated network designs in which passengers can take advantage of very efficient trip legs while not paying significantly more for their fare.'*
4. **Image** *'results in a common presentation of the system in a way which indicates that all the different services belong to the same system'*
5. **Institutional** *'involves management agencies coordinating the activities, hopefully under a single authority for strategic planning and oversight'*

Hidalgo et al suggest that implementation of an integration framework requires objective driven management through creating an independent and empowered implementation team. Santiago set the overarching goal of fare integration using a '**Big Bang**' (fast) approach, whilst Bogota elected for a '**gradual**' (slower) approach to try and combat stagnating patronage.

In the case of Edmonton, the delivery of most transit services through the one agency, ETS, should reduce the likelihood of non-integrated service. However significant challenges remain with respect to physical and operational integration, particularly with respect to the the future role Transit Centres ought play, should BRT be implemented (cf. Section 5.4.1), as well as the significant issue of fare policy. There is a strong policy justification for revising fare policy to take account of the likely additional service delivery costs associated with BRT and in particular whether distance based fares are warranted and technologically possible.

It is also arguable that a greater level of institutional integration could be achieved by revising the the legislation that governs Capital Region municipalities, the CRB and the Government of Alberta and better defining responsibilities with regards to infrastructure planning and service provision, particularly in the context of regional transit and seeking to ensure that there is effective transit service delivery and forward planning on major transportation corridors as the region grows.

5 PERMANENT BRT AS A POTENTIAL ELEMENT OF A MULTI-MODAL TRANSIT NETWORK IN EDMONTON

This section discusses preliminary options for further consideration as part of any future evaluation of permanent BRT as a potential element of a multi-modal transit network. This discussion includes the potential for using BRT as a long term solution in corridors where LRT is not currently planned.

5.1 APPLICABLE BRT CONCEPTS

Based on the lessons outlined in this paper, three BRT options have been considered worthwhile for preliminary discussion purposes (cf. Table 3):

- The first is a BRT “light” concept referred to as **Premium Bus** service and includes the features of a rapid transit service (cf. Section 2.1). This service falls below the ITDP’s BRT Standard definition (cf. Section 2.2.1) but includes some service and infrastructure recent projects described as BRT in the North American context.
- Second is **Interim BRT** (“pre-LRT” or BRT as a precursor to LRT), which includes most of the features found in the ITDP BRT Standards primarily because infrastructure must be designed to accommodate future LRT trackway and station infrastructure.
- Finally, **Permanent BRT** is described as service and infrastructure with characteristics of BRT found in the ITDP-rated BRT systems in North America.

The characteristics shown for BRT as pre-LRT and Permanent BRT are intended to match the requirements the Edmonton LRT system; that is, full BRT is intended to be functionally equivalent to LRT in infrastructure and service. They have been adjusted to fit into the existing Edmonton context.

For reference purposes, the classification of many of the existing BRT services in North America, according to the ITDP and other organisations, can be found in Appendix A.

Table 3 - Three potential BRT Concepts for Edmonton

Service Type and Component	Premium Bus (BRT "light")	Interim BRT (pre-BRT or LRT)	Permanent Bus Rapid Transit
Likely Corridors	Radial (downtown) corridors more than 2km from LRT corridors and crosstown corridors linking LRT lines.	Radial corridors identified as future rail corridors in the LRT Network Plan.	Major crosstown corridors linking LRT lines, particularly those served by regional buses.
Service Levels	At least 200% of connecting rail service	Equal to Rail Service (Long-Term)	Equal to Rail Service (Long-Term)
Mixed Traffic Lanes Including Queue Jump Lanes	Yes	As an Interim Step in LRT ROW Acquisition	Less than 25% of BRT Alignment
Dedicated BRT Lanes Arterial or Highway	Peak or All-Day Median or Curbside Lanes in Congested Segments	Two-Way, All-Day Median BRT Lanes	Two-Way, All-Day Median BRT Lanes
Stops and Stations	Single Bus Stops with Branded Shelters	Platforms Extendable to Operating Train Lengths with LRT Station Shelters and Amenities	30m Platforms with LRT-style Station Shelters and Amenities**
Off-Board Fare Collection	Preferable	Yes	Yes
Transit Signal Priority	Yes	As Required*	As Required*
Platform Level Boarding	Yes, at Curbside or Median Stops	Yes, at Median Stations***	Yes, at Median Stations
All-Door Boarding	Preferable	Yes	Yes
Distinct Service Brand	Preferable	No (same as LRT)	No (same as LRT)
Upgraded Stops and Shelters	Yes	Yes	Yes
Hours of Two-Way Operation	At Least 12 Hours on Weekdays	Equal to LRT Service Periods	Equal to LRT Service Periods

*TSP as required in mixed corridors or at roadway grade crossings.

**A 30m platform is normally sufficient to hold a single articulated bus or two standard buses.

***Platforms may require custom or interim design to support long-term conversion to LRT.

5.2 RIGHT OF WAY AND BASIC STREETScape DESIGN CONSIDERATIONS FOR BRT

The conceptual design features of any busway depend to a large degree on its implementation context. The Capital Region Board is currently identifying the potential for High Occupancy Vehicle (HOV) Lanes in the Capital Region by conducting a detailed study of HOV feasibility study on specific corridors. The assessment will include recommendations on whether such facilities should operate exclusively as bus lanes or with mixed traffic. A report is due in late 2016.

For the purposes of the discussion here, the roadway shown in Figure 16 is assumed to be the starting point for general ROW considerations for BRT. It depicts a typical arterial roadway in Edmonton in conceptual form.

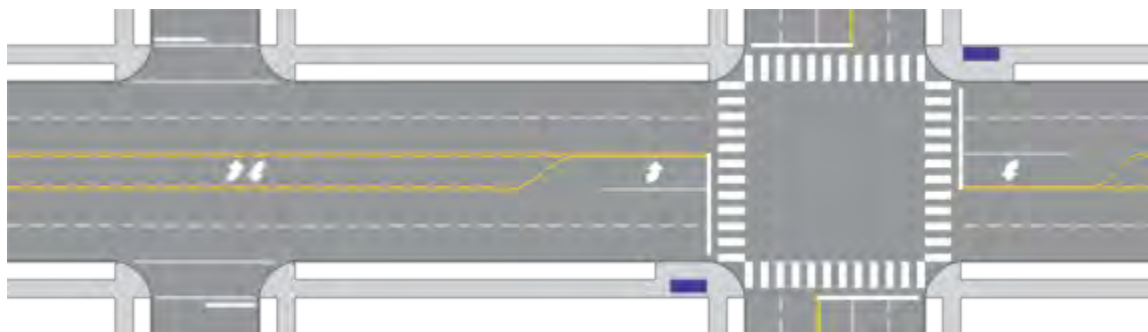


Figure 16 - Typical arterial roadway in Edmonton

A typical arterial roadway in Edmonton includes two or three lanes in each direction and may include a centre turning lane, sidewalks, signalised intersections and crosswalks. Edmonton's Design and Construction Standards (Volume 2: Roadways) often provide for a generous right-of-way, allowing sufficient space for alternative mobility designs.

5.2.1 SHOULDER BUS LANES

Figure 17 depicts a roadway with Shoulder Bus Lanes. As noted in section 2.5, Transit Signal Priority (TSP) is one proven method to assist with improving transit travel speeds and flow. Where feasible and warranted, intersection queue jumps can also be included in infrastructure design. Cycle lanes with enhanced active transportation infrastructure may be considered in inner urban areas as part of a Complete Streets concept⁷. A typical illustrative urban roadway cross section is included in Figure 18.

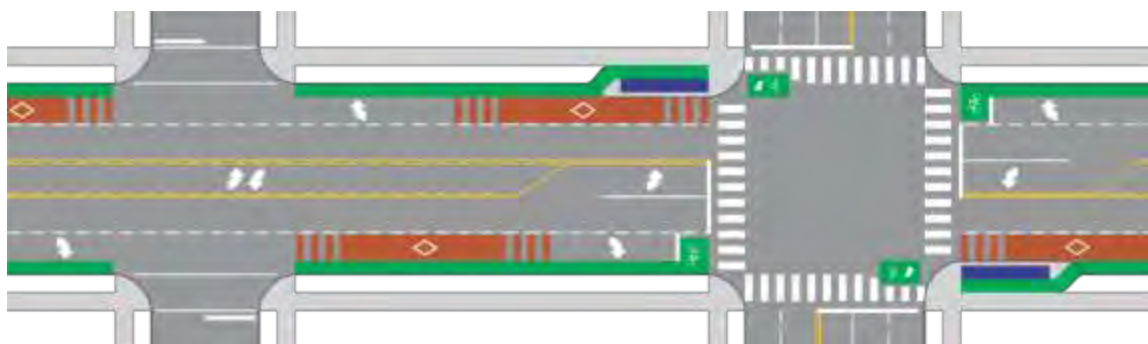


Figure 17 A Premium Bus Street with Shoulder Bus Lanes

Where possible, Premium Service arterials should incorporate bus lanes throughout the corridor or in congested segments.

⁷ The example shown is purely for illustrative purposes and to demonstrate the potential interaction between cycle lanes and shoulder bus lanes.

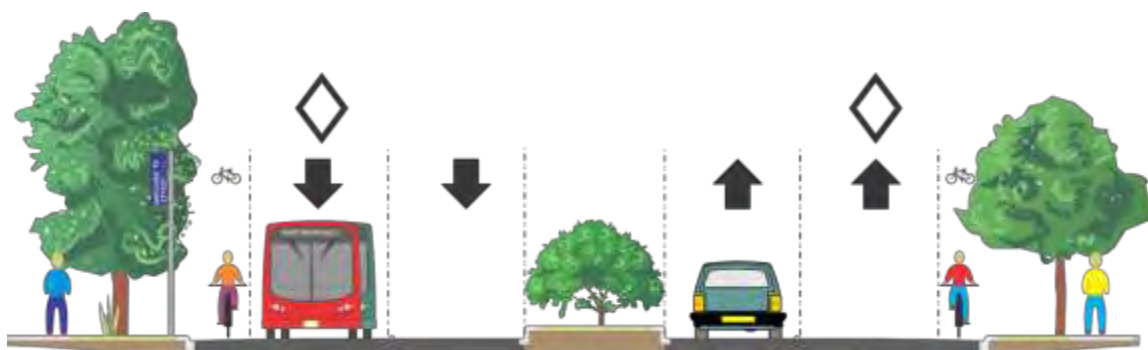


Figure 18 - A Premium Bus Street with a median and Shoulder Bus Lanes (inner urban setting, cycle lanes included for illustrative purposes)

5.2.2 BRT ARTERIAL WITH MEDIAN BUS LANES

Considerations for a BRT arterial with median bus lanes vary depending on factors such as bus headways, amount of road space allocated for BRT and platform configurations. In this conceptual example, BRT uses a median arterial with staggered stops. This allows a greater number of turning movements from other roadway users.

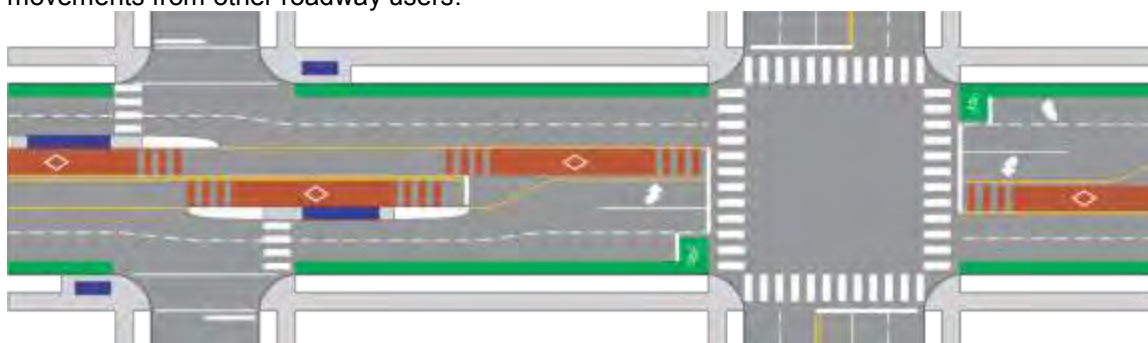


Figure 19 - Figure 5 – A Limited Frequency Permanent BRT Arterial with Median Bus Lanes and Staggered Stops

This conceptual design may be altered to accommodate island platforms. This has the effect of restricting other vehicle movements, but also increasing capacity and affording more transit priority to buses.

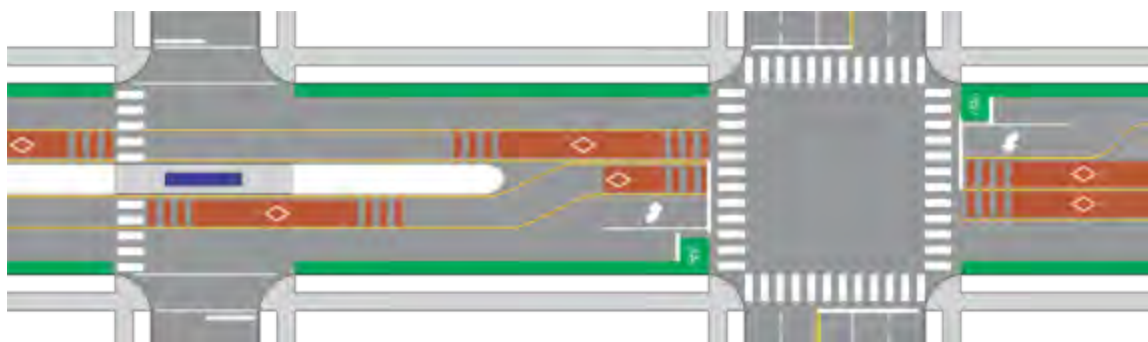


Figure 20 - Permanent BRT arterial with island platforms

Permanent BRT corridors and BRT corridors designed for future conversion to LRT require additional right-of-way and must accommodate trackway geometry, stations, and related infrastructure.

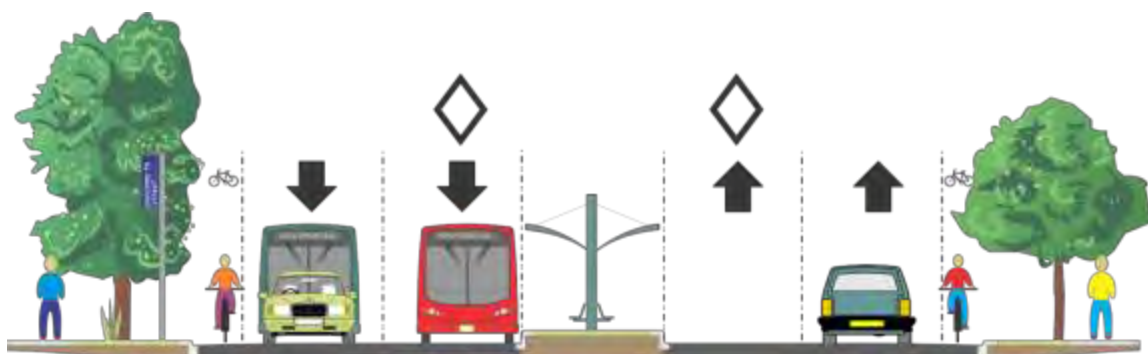


Figure 21 - A BRT Arterial with Median Bus Lanes

Most BRT corridors can be designed to accommodate the rail guideway, but the different design guidelines for Regional LRT and Urban LRT must be considered in the busway geometry and right-of-way width.

The BRT arterial with Median Bus Lanes concept has the advantage of being more easily converted or upgraded to LRT. But it is also in most instances likely to be the most expensive of three designs outlined here.

5.3 POTENTIAL BRT NETWORK CONCEPT

5.3.1 ASSUMPTIONS

The development of a potential network concept is designed to generate discussion and ideas about what possible role BRT could play in Edmonton in the future and how this may be realised. The scope of this paper only allows a 'high-level' discussion of technical aspects and it is necessary to employ a number of assumptions to illustrate this concept. In doing so, it seeks to adopt a number of common BRT design and operating characteristics as outlined in this paper but also draws on current operating practices within the present Edmonton transit network.

For purposes of developing a potential network concept, the following assumptions have been adopted:

1. At least one of the three options could be implemented in a number of the major arterial corridors in Edmonton.
2. To avoid competition with the existing LRT network, a radially-oriented Premium bus service is assumed to be at least two kilometres away from a parallel LRT corridor, while a crosstown Premium Bus corridor could operate in any high demand bus corridor but should connect to the LRT station at a key destination hub.
3. BRT as a precursor to LRT could take the form of a busway in the median of an arterial or another reserved corridor (such as a hydro corridor or abandoned rail corridor) specifically where an LRT extension is planned. The BRT would begin at an existing LRT station and continue along the future LRT alignment to a logical terminal station, and BRT design would be designed in a manner that would be able to accommodate future LRT geometry and the other considerations, outlined in Chapter 3.
4. Permanent BRT corridors could also be developed over time, but it is assumed that these should be complementary to the LRT network and avoid competing with existing LRT infrastructure.
5. Permanent BRT corridors could be major crosstown corridors, including those along freeways or in other dedicated rights-of-way.
6. BRT ROW and corridor characteristics are consistent with those illustrated in Figures 16-21, which are assumed to be typical arterial roadway characteristics in Edmonton.

5.3.2 POTENTIAL MULTI-MODAL NETWORK CONCEPT WITH BRT

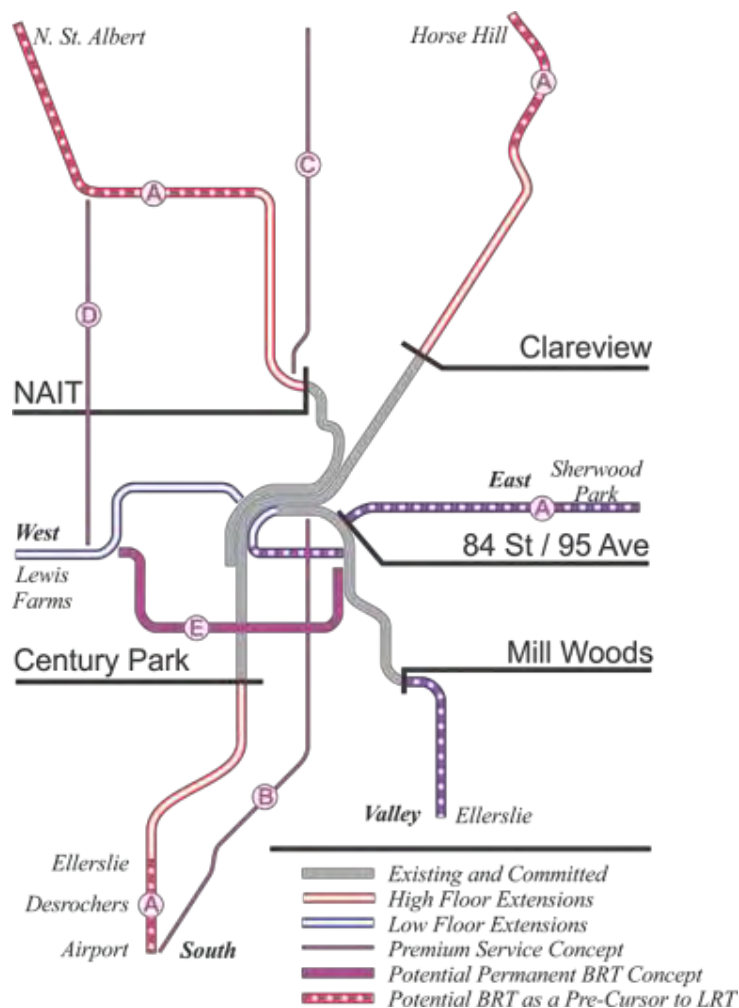


Figure 22 - Potential multi-modal Network Concept with BRT

5.3.3 NETWORK RATIONALE

The following rationale has been used to justify the network concept (cf. Figure 22) and the coverage proposed here:

1. BRT improvements ought to provide a high degree of connectivity to the core LRT network.
2. Premium service corridors serve the suburb-to-city centre commute in corridors not served by LRT (illustrated as line “B”) or in crosstown corridors between the LRT system and secondary suburban centres (illustrated as lines “C” and “D”).
3. In some suburban LRT corridors, BRT as a Pre-Cursor to LRT could preserve right-of-way for longer-term LRT implementation while building ridership for the full buildout of the LRT network plan (represented as lines marked “A”). Where BRT is built as a Pre-Cursor to LRT, the BRT corridor must be designed to the appropriate standard for the high floor or low floor systems and reserve right-of-way for LRT stations, traction power substations, and other related infrastructure

4. Permanent BRT would be focused on crosstown arterial and highway corridors designed to provide high quality integration with the LRT system (illustrated as line “E”). These corridors are envisioned as high quality, frequent bus connectors with dedicated busway infrastructure that connects major suburban centres with the LRT network.

5.4 STAGED MODAL INTEGRATION

5.4.1 TRANSIT NETWORK STRUCTURE DESIGN AND OPERATING CHARACTERISTICS

Future network structure and design would need careful consideration as part of any move towards BRT. The current bus network is based largely a territorial network operating on a **‘focal point transfer basis’**, also known as the **‘pulse concept’** (cf. Figure 23, left hand side). In this case, loops covering a catchment are timed to ensure buses return to the network hub in time for departures or arrivals at key nodes on the network. In the case of Edmonton, hubs are generally one of the 25 Transit Centres, however only 8 of these are currently associated with LRT.

The advantages and disadvantages of such a system are discussed in detail in the *Edmonton Transit System Comprehensive Review* (Stantec Consulting, Jarrett Walker & Associates et al. 2013). These considerations were also further highlighted and discussed as part of the 2014 *Edmonton Transit Report on Steps Towards a Decision on Strategic Planning* (Stantec Consulting and Jarrett Walker and Associates 2014). Instead of explicitly considering BRT, Jarrett Walker advances the notion of the ‘Very Frequent Transit Network’ service delivery model in that report.

Staged modal integration is an similar transit planning approach that seeks to not only identify key transit corridors that are designed to receive a certain level (frequency) of transit service, but is also designed to integrate any new BRT services with existing transit operations in order to minimise operational inefficiencies such as dead running. Staged modal integration speaks to the fundamental aim of BRT to provide ‘rapid transit’ whilst incorporating the role and function of other modes. Through the adoption of **trunk routes** (cf Figure 24), an appropriate **integration framework**, (as advanced in section 4.3.1) and appropriate **rights of ways**, (cf. section 5.2) a new BRT concept with rapid transit speeds and frequencies could be achieved.

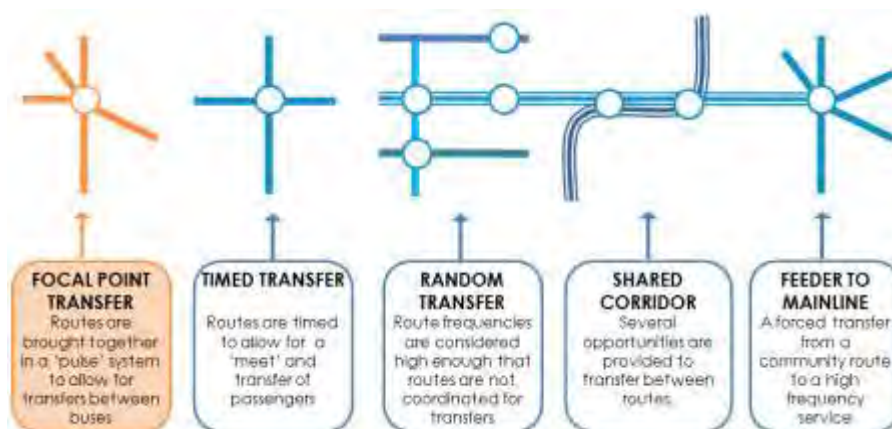


Figure 23 – Transfer types

Figure 23 depicts different transfer types for transit. Edmonton currently uses the focal point transfer system for the majority of bus services.

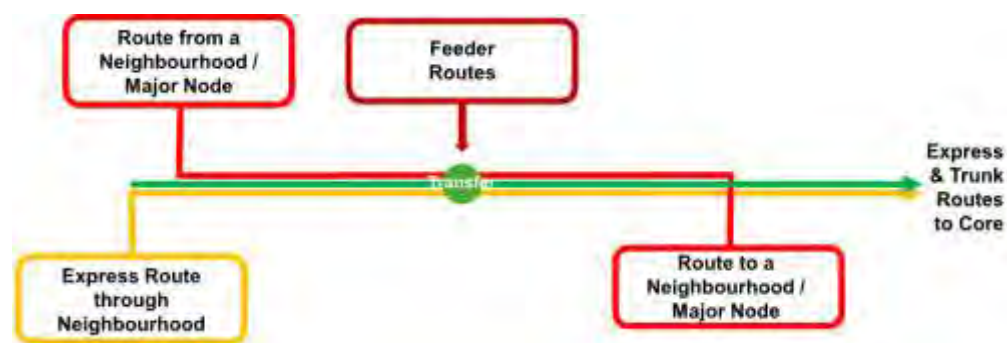


Figure 24 – Example of modal integration model using trunk routes to support rapid (express) transit

Figure 24 introduces the trunk concept for operating rapid transit. This concept incorporates express (including rapid) routes and in particular seeks to redefine the role of a transfer point on the network. It is designed with sufficient flexibility to be multimodal in nature and does not treat any one mode as operating in isolation. It can easily be supplemented by soft mobility concepts that incorporate enhanced active transportation (walking and cycling, including bike share) opportunities near transfer points (cf. Figure 25). Land uses with appropriate terminal facilities and strategic consideration of relative consumptive impacts of land for any facilities and around transfer points become key points of consideration as part of this approach, emphasising the need for integrated transportation and land use planning⁸.



Figure 25 - Oldenburg Hauptbahnhof (Main Train Station), Lower Saxony, Germany

Oldenburg's Main Train Station provides direct connections to the local and regional bus network, ample bicycle parking (both unsupervised and supervised), cell-phone activated bike rental, café and restaurants, park and ride for private motor vehicles (subject to a fee), taxi bays as well as easy access to the local cycling network.

5.4.2 STEPS TO CONSIDER FOR BRT AS PART OF STAGED MODAL INTEGRATION

The Staged Modal Integration Concept could be realised over time by using the following steps.

STEP ONE – DEVELOP BRT DESIGN AND SERVICE GUIDELINES

BRT Design and Service Guidelines would outline the basic BRT service elements for the Edmonton Transit System (ETS) that convey the idea of a 'network hierarchy' similar to the 'Very Frequent' and 'Frequent Transit Network' network recommended by the 2013 Edmonton Transit System Comprehensive Review. Under this approach, the key objectives of BRT would be a network design that enables frequent and reliable service with high quality connections to the LRT system and local bus network.

⁸ *Terminal facilities* refer to transportation infrastructure that can 'store' vehicles when they are not being used, including bus transfer stations (specifically waiting bays during layovers), bicycle parking and park and ride facilities.

STEP TWO – IDENTIFY CANDIDATE BRT CORRIDORS FOR IMPLEMENTATION

Figure 26 illustrates how BRT might be expanded and integrated into the Edmonton context at a whole of network, high-level conceptual level. In all cases, BRT improvements must provide a high degree of connectivity to the core LRT network (represented as line “A”).

Premium service corridors can serve the suburb-to-city centre commute in corridors not served by LRT (illustrated as line “B”) or in crosstown corridors between the LRT system and secondary suburban centres (illustrated as line “C”).

In some suburban LRT corridors, BRT as a Pre-Cursor to LRT may preserve right-of-way for longer-term LRT implementation while building ridership for the full build out of the LRT network plan (represented as line “D”). Where BRT is built as a Pre-Cursor to LRT, the BRT corridor must be designed to the appropriate standard for the high floor or low floor systems and reserve right-of-way for LRT stations, traction power substations, and other related infrastructure. As indicated in Figure 22, the interim BRT service must provide for a high quality transfer to the LRT system. Where Pre-Cursor to LRT is not contemplated or not able to be funded in the foreseeable future, the alternative exists to operate a Premium Bus on existing roadway instead with TSP.

Finally, the concept of permanent BRT is most likely focused on crosstown arterial and highway corridors designed to provide high quality integration with the LRT system (illustrated as line “E”). These corridors are envisioned as high quality, frequent bus connectors with dedicated busway infrastructure that connects major suburban centres with the LRT network.

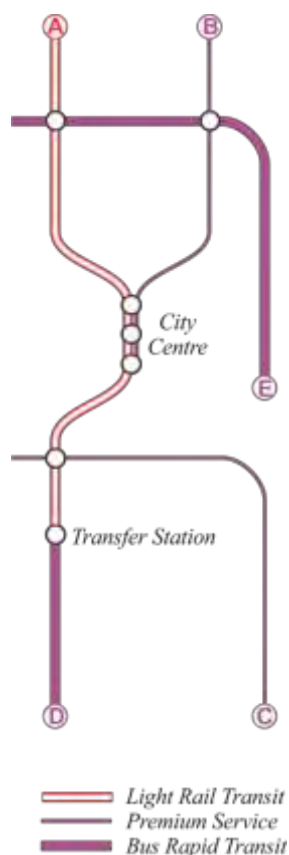


Figure 26 - Potential interactions and Integration between BRT and LRT

5.5 CASE STUDIES: EUGENE AND SALT LAKE CITY

The following represents two case studies concerned with implementing two different BRT operational concepts, in this case Premium Bus operating in varying urban environments and on different ROWs.

Eugene's EmX and Salt Lake City's 3500 South MAX are considered two variants of BRT systems that could be considered applicable to potential BRT considerations in Edmonton context for the following reasons:

1. They operate on busway segments that include two-way and bidirectional bus lanes
2. They contain Transit signal priority (TSP),
3. Limited stops (typically only at major transit connections and key destinations) are present
4. They contain a Distinct brand identity (BRT name, logo, and bus livery),
5. Larger buses (MAX has longer and wider 3-door buses; EmX has articulated buses with boarding doors on both left and right sides) are used
6. Bus lanes along portions of the route are used only by BRT service (some mixed traffic service), and
7. Prepaid fares are required.

5.5.1 SALT LAKE CITY

In Salt Lake City, Utah, the 3500 South MAX is the first of four planned BRT lines for the urban area. Planned routes include the Provo-Orem MAX, the 5600 West MAX, and the Murray-Taylorville MAX. MAX service largely operates as rapid bus service in mixed traffic, but congested portions of MAX corridors include dedicated median bus lanes, and it operates a headway based schedule with no time points, allowing it to travel from one end of the route to the other without added dwell time to maintain its schedule.

MAX service also operates on a timed transfer schedule to meet inbound trains at the Mill Creek TRAX (LRT) station (the route also connects with LRT at the West Valley Intermodal Hub). MAX is also distinct from other BRT systems in that the bus lanes generally include a lane in each direction but, in areas of constrained right-of-way serve both directions of MAX service in a single bidirectional median lane. Where MAX enters service on a bidirectional lane, access is controlled through signalization with oncoming buses stopping at designated areas.

In conceptual terms, the 3500 MAX a good example of a BRT service that could be implemented and operated on the "A" lines in as part of a pre-cursor to LRT (cf. Figure 22). However, it should be noted that is unlikely to be viable on its own custom-built exclusive ROW as there are likely to be a limited number of existing freeway-type arterials in the Edmonton Metropolitan Area that are designated to be converted to LRT in the long term as part of the LRT Network Plan.

Instead, if the CRB HOV study currently underway were to recommended reallocating arterial and freeway space using TPV, then this particular BRT concept may warrant further consideration. However, as the functional planning for both the St Albert and Sherwood Park LRT lines are both at different stages at present, this makes implementing this concept for pre-cursor BRT purposes more difficult. Furthermore, a significant amount of land use planning would need to be undertaken to ensure modal and urban integration with surroundings.



Figure 27 - South MAX BRT, Salt Lake City

SUMMARY

- Pros:** Reasonable ridership (4100 ppd), good example of Premium BRT with partial exclusive ROW operating on arterial roads, innovative use of existing road space
- Cons:** Does not appear to be so well suited to inner urban (constrained) environments

5.5.2 EUGENE

In Eugene, Oregon, EmX service operates in a variety of contexts, including mixed traffic, dedicated bus lanes on one-way streets, median bus lanes, bidirectional bus lanes, and landscaped bus lanes. Where EmX enters service on bidirectional lanes, BRT passing lanes are provided at key locations to support bidirectional service. EmX is unique in North America in providing both left and right boarding doors, allowing BRT to serve center platform stops throughout its route.

Neither MAX nor EmX services are envisioned to be converted to LRT service, but both offer innovative design solutions to solve constraints and enhance the transit experience in their specific contexts. In Salt Lake, MAX provides smaller communities and suburban areas with access to the regional TRAX LRT system. In Eugene, EmX provides a “rail-like service” in a small city context.



Figure 28 - Eugene EmX Service

SUMMARY

- Pros:** Flexible deployment of Premium Bus BRT operating in various urban environments
- Cons:** Smaller city, lower peak load (500 pphpd), custom vehicles required, lower ridership, no dedicated right of way

6 CONCLUSION

This paper has sought to outline and explore a number of key transportation planning considerations that would be necessary as part of any move towards Bus Rapid Transit (BRT) in the Edmonton Metropolitan Region. BRT is shown to be a popular rapid transit mode that has its roots in North American busways that were constructed in the late 1960's. By the mid 1970's this concept had been adopted in South America where it quickly gained significant ridership and prominence before quickly spreading to many other cities on the continent. More recently, BRT has found widespread support and popularity in Asia. Meanwhile in Canada, Ottawa pioneered the Transitway in 1983 here in Canada. More recently BRT has been adopted with success in Winnipeg and variants also exist in other Canadian cities such as Vancouver, Calgary, Quebec City and Halifax. Ottawa has the distinction of being a BRT system that outgrew its capacity after 30 years and is now tackling the difficult issue of upgrading to LRT to secure next generation capacity, however it is universally acknowledged that this has not been without its issues.

Despite the above success stories noted above, one of the most fundamental problems that remains in evaluating BRT is understanding what it is and what it can do for a city to improve its transportation system efficiency and performance. BRT systems and their application vary widely, along with urban form of cities, making it difficult to conduct direct comparisons. Projects such as BRTdata.org and other well-resourced research initiatives help to demystify the benefits and create a common reference point and benchmark for discussion.

Edmonton is embarking on an ambitious plan to increase transit ridership and decrease automobile dependency by expanding the existing LRT network over the next several decades. As LRT is a capital intensive form of transportation infrastructure, this raises the question of whether BRT can be introduced at a more affordable cost and potentially act as a precursor to LRT on some transportation corridors. This would have a number of potential and tangible benefits, especially in terms of helping to play a role in achieving *The Way We Move* targets: better integration between transportation and land use, enhanced access and mobility, mode shift and a healthier Edmonton, amongst others.

This paper examined a number of issues inherent both in adopting BRT on a temporary or permanent basis, including – but not necessarily limited to – the likely ridership potential of BRT (both in peak hour and daily ridership terms), the relative difference between capital and operating costs, case studies with design considerations where conversion from BRT to LRT has been (or is being attempted) as well as the changes to network design and operation that are inherent in a shift to a rapid transit, well-integrated, multi-modal network. A number of concepts were presented that demonstrate the nature of those changes and how they might be realised on a corridor by corridor basis or at a whole of network level.

In addition to the above and as to better demonstrate how this would translate into a new service delivery model specific to the Edmonton context, Premium Bus, Interim BRT and Permanent BRT concepts were presented based on some assumptions at the whole-of-network level. The relative merits of each model was demonstrated using a hypothetical, staged modal integration concept.

Based on the information presented, but also in recognition of the broad nature of many of the transportation planning considerations presented here for discussion purposes at this stage of the ongoing Transit Strategy, it is considered that the BRT concept is worthy of further detailed evaluation. This evaluation could draw on much of the information presented here. Such an evaluation would be well suited to either an existing transportation corridor in Edmonton with either significant increased transit ridership potential or an existing LRT Network Plan corridor once the results of the City's current LRT Prioritization have been finalised later this year.

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Appendix A

**CLASSIFICATION OF BRT SYSTEMS IN NORTH AMERICA ACCORDING TO
5 DIFFERENT SOURCES**

	Source 1: ITDP Project Rating	Source 2: Canada/US	Source 3: Canada	Source 4: Int'l 2001 Report	Source 4: US 2012 Report	Source 5: US
Albany, NY (Bus Plus)	<i>Not BRT</i>		<i>n/a</i>		Included	
Boston, MA (Silver Line)	<i>Not BRT</i>	Included	<i>n/a</i>	Included		
Brampton, ON (ZUM)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Calgary, AB (301/302)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Charlotte NC (Independence)	<i>Not BRT</i>		<i>n/a</i>	Included		
Cleveland, OH (Euclid/HealthLine)	Silver	Included	<i>n/a</i>	Included	Included	
Dallas, TX (Express Bus)	<i>Not BRT</i>		<i>n/a</i>	Included		
Dallas, TX (HOV Express)	<i>Not BRT</i>		<i>n/a</i>	Included		
Denver, CO (HOV express)	<i>Not BRT</i>		<i>n/a</i>	Included		
Eugene, OR (EmX)	Bronze		<i>n/a</i>	Included	Included	
Flagstaff, AZ (MountainLinks)	<i>Not BRT</i>		<i>n/a</i>		Included	
Gatineau, QC (RapiBus)	<i>*NEW*</i>		Included	<i>n/a</i>	<i>n/a</i>	
Guadalajara, Jal. MX (Tunnel)	<i>Converted</i>		<i>n/a</i>	<i>n/a</i>	<i>n/a</i>	Included
Hartford, CT (New Britain Busway)	<i>Not BRT</i>		<i>n/a</i>	Included		
Honolulu, HI (CityExpress HOV)	<i>Not BRT</i>		<i>n/a</i>	Included		
Houston, TX (HOV express)	<i>Not BRT</i>	Included	<i>n/a</i>	Included		
Kansas City, MO (Troost Max)	<i>Not BRT</i>		<i>n/a</i>		Included	
Las Vegas, NV (Line BHX Express)	<i>Not BRT</i>		<i>n/a</i>		Included	
Las Vegas, NV (SDX)	Basic		<i>n/a</i>			
Livermore, CA (Rapid)	<i>Not BRT</i>		<i>n/a</i>		Included	
Los Angeles, CA (Orange Line)	Bronze		<i>n/a</i>			
Los Angeles, CA (Rapid)	<i>Not BRT</i>	Included	<i>n/a</i>		Included	Included
Miami, FL (Busway)	<i>Not BRT</i>	Included	<i>n/a</i>	Included		Included
Mississauga, ON (Transitway)	<i>*NEW*</i>		Included	<i>n/a</i>	<i>n/a</i>	
New York, NY (M15)	<i>Not BRT</i>		<i>n/a</i>		Included	
Oakland, CA (Rapid)	<i>Not BRT</i>	Included	<i>n/a</i>			
Ottawa, ON (Transitway)	Bronze		Included	<i>n/a</i>	<i>n/a</i>	
Pittsburgh, PA (MLK East Busway)	Bronze	Included	<i>n/a</i>			
Pittsburgh, PA (South Busway)	Basic		<i>n/a</i>			
Pittsburgh, PA (West)	Basic		<i>n/a</i>			

	Source 1: ITDP Project Rating	Source 2: Canada/US	Source 3: Canada	Source 4: Int'l 2001 Report	Source 4: US 2012 Report	Source 5: US
Busway)						
Quebec, QC (Metrobus)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Reno, NV (RTC Rapid)	<i>Not BRT</i>		<i>n/a</i>		Included	
Salt Lake City, UT (35M)	<i>Not BRT</i>	Included	<i>n/a</i>			
San Bernardino, CA (sbX)	Bronze		<i>n/a</i>			
San Diego, CA (HOV express)	<i>Not BRT</i>		<i>n/a</i>	Included		
San Joaquin, CA (Line 44 Express)	<i>Not BRT</i>		<i>n/a</i>		Included	
San Jose, CA (Line 22 Rapid Transit)	<i>Not BRT</i>		<i>n/a</i>	Included		
San Juan, PR (Rio Hondo)	<i>Not BRT</i>		<i>n/a</i>	Included		
Saskatoon, SK (DART)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Seattle, WA (Downtown Seattle Transit Tunnel/SODO Busway)	Bronze		<i>n/a</i>			Included
Seattle, WA (Rapid Ride)	<i>Not BRT</i>		<i>n/a</i>		Included	
Toronto, ON (TTC 196)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Vancouver, BC (98 B-Line)	<i>Converted</i>	Included	<i>n/a</i>	<i>n/a</i>	<i>n/a</i>	
Vancouver, BC (99 B-Line)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Washington, DC (Dulles HOV)	<i>Not BRT</i>		<i>n/a</i>	Included		
Washington, DC (Shirley Busway)	<i>Not BRT</i>		<i>n/a</i>			
Waterloo, ON (iXpress)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
Winnipeg, MB (SW RTC)	<i>Not BRT</i>		Included	<i>n/a</i>	<i>n/a</i>	
York Region, ON (Viva)	<i>*NEW*</i>		Included	<i>n/a</i>	<i>n/a</i>	

Sources:

Source 1: ITDP Standard Scores, 2013-2014 (Only Canada/US shown)

Source 2: Deng and Nelson, *Transport Reviews*, Vol. 31, No. 1, pp. 69-96, Jan 2011

Source 3: *Federal Support for Bus Rapid Transit and Light Rail Transit Systems in Canada (2010-64-E)*, 2010

Source 4 (2001): United States General Accounting Office (GAO), *Bus Rapid Transit Shows Promise, 2001*

Source 4 (2012): United States General Accounting Office (GAO), *Projects Improve Transit Service and Can Contribute to Economic Development*

Source 5: Henry and Dobbs, *Bus Rapid Transit as a Precursor to Light Rail Transit*, Transportation Research Circular E-C145, 2010

Appendix B

**COST ESTIMATING MODEL FOR MODE CHOICE BETWEEN LIGHT RAIL AND
BUS RAPID TRANSIT SYSTEMS, HSU (2013)**

		LRT-1	LRT-2	BRT-1	BRT-2 (articulated bus)
Input	Route length (mi)			14.6	
	Passenger demand (pphd)			3,400	
	Number of stops and stations			16	
	Operating hour (h)			20	
	ROW (%)		ROW A: 68, ROW B: 0, ROW C: 32		
	Alignment (%)		at grade: 97, elevated:3		
	Vehicle passenger capacity				
Passengers per vehicle	190	250	45	67	
Seats per vehicle	68	190	50	74	
Peak headway (min)	10	10	3	3	
Output	Number of vehicles required ^a	42	31	118	74
	Capital cost (millions of dollars)	509.1	477.0	311.0	257.0
	Millions of dollars per mile	34.8	32.7	21.3	17.6
	OM cost (millions of dollars)	27.0	21.6	62.4	38.4
	Depreciation cost (millions of dollars) ^b	29.6	27.1	31.2	24.1
	Total annual costs (millions of dollars) ^c	56.5	48.6	93.6	62.5
	Dollars per passenger mile	0.146	0.125	0.242	0.162

Note: Year 2000 costs are escalated to year 2010 using 1.26 escalation rate. 1 mile = 1.609 km. Costs are in year 2010 U.S. dollars.

^aNumber of vehicle required is estimated by applying Eq. (1).

^bDepreciation cost = annualized capital cost.

^cTotal annual costs = depreciation cost + OM cost.

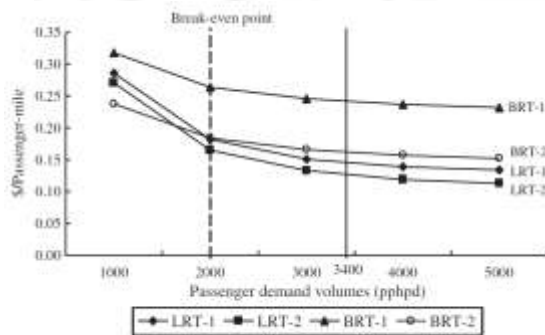


Fig. 1. Comparative analyses

Table 9. Capital and OM Costs with Respect to Variables in the Cost Estimating Model: Alignment Configuration

System	Alignment (%)			Capital cost (millions of dollars per mile)	OM cost (millions of dollars)
	At grade	Elevated	Tunnel		
LRT	100	0	0	32.0	24.9
	50	50	0	37.2	24.9
	40	50	10	45.9	24.9
	40	40	20	53.5	24.9
	40	30	30	61.2	24.9
BRT	100	0	0	17.4	57.6
	50	50	0	40.3	57.6
	40	50	10	62.2	57.6
	40	40	20	78.9	57.6
	40	30	30	95.9	57.6

Table 8. Capital and OM Costs with Respect to Variables in the Cost Estimating Model: Route Length

System	Route length (mi)	Capital cost (millions of dollars per mile)	OM Cost (millions of dollars)
LRT	5	47.1	12.9
	10	35.8	19.1
	15	32.1	25.4
	20	30.2	31.6
	25	29.1	37.6
BRT	5	32.0	26.8
	10	22.7	42.8
	15	19.6	58.9
	20	18.0	74.9
	25	17.1	91.0

Table 10. Capital and OM Costs with Respect to Variables in the Cost Estimating Model: Row Configuration

System	ROW (%)			Fleet size (vehicles)	Capital cost (millions of dollars per mile)	OM cost (millions of dollars)
	A	B	C			
LRT	100	0	0	37	31.5	23.8
	40	50	10	40	32.0	24.6
	20	60	20	41	32.4	25.0
	5	65	30	43	32.7	25.4
	5	95	0	40	32.1	24.6
BRT	100	0	0	94	18.0	52.6
	40	50	10	108	19.1	55.8
	20	60	20	116	19.8	57.7
	5	65	30	124	20.4	59.5
	5	95	0	108	19.1	55.7

Note: Passenger demand volume = 3,400 pphd; route length = 14.6 mi; number of stations and stops = 16; LRT . 68 seats/vehicle, 2.8 passengers/seat; BRT . 50 seats/vehicle, 0.9 passengers/seat; 1 mile = 1.609 km. costs are in year 2009 U.S. dollars.

APPENDIX B-1

TITLE

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