NORTH–SOUTH CORRIDOR LRT PROJECT

(Rideau Centre to Barrhaven Town Centre)

Overview Assessment of Rail and Bus Technologies

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APPENDICES

1.0 Introduction

This report is one of several background working papers prepared as part of the development of the Environmental Assessment Study for the extension of rapid transit service from the limits of the present O-Train service north and east into downtown Ottawa and south and west serving the developing areas of Riverside South and Barrhaven.

Previous analysis determined that transit is the most appropriate solution in the study corridor and that, to accommodate the forecast demand in 2021 of some 60,000 to 70,000 daily riders, rapid transit is the most appropriate solution. The purpose of this report is to review the realistic potential rapid technologies for this corridor and to select a preferred and appropriate transit mode. Heavy rail (subway or metro) is not an appropriate technology for the projected ridership in this corridor so this report focuses specifically on comparing Light Rail Transit (LRT) with Bus Rapid Transit (BRT)

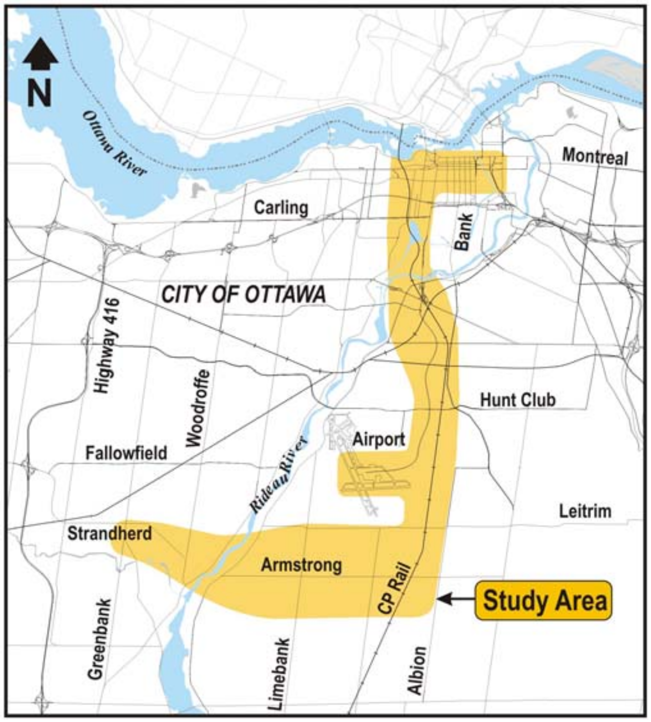
The report provides a background to the corridor under consideration, provides an overview of LRT and BRT, illustrates several LRT and BRT systems and then provides a comparison of LRT and BRT specific to Ottawa's north-south rapid transit corridor under consideration.

2.0 Nature of the Study Corridor

The geographic limits of the Environmental Assessment study area for the development of the undertaking can be divided into four main corridors, which include:

- A downtown section from Rideau Centre to LeBreton Flats;
- A North-South section from LeBreton Flats to south of Leitrim Road along an existing railway corridor;
- A westerly spur into the Airport; and
- An East-West section running from the CPR corridor south of Leitrim Road southwest to the Limebank Road area, along with a westerly extension across the Rideau River to Barrhaven Town Centre.

The boundaries of the Study Area are illustrated in the adjacent key map.



The study corridor is approximately 31 km. long. A major component of the corridor (the north-south section) runs along an existing (CPR) railway line. The remaining portions of the corridor run along existing city streets into the downtown and along future urban streets serving the developing urban areas to the south.

After an earlier environmental assessment approval, a Light Rail Pilot Project known as the O-Train was implemented within the north portion of the railway corridor. The service is operated with 2 (plus 1 spare) Bombardier Talent DMU trains. This pilot project has been operational since October 2001 and presently runs between the Greenboro and Bayview Stations serving Carleton University and the Federal Government office complex at Confederation Heights and Carling Avenue.

After 18 months in operation and an investment of $30 million, the O-Train has been judged a success. Ridership has generally exceeded expectations with more than 8000 riders per weekday. The public feedback has been positive.

Based on the success of the Light Rail Pilot Project, a previous Rapid Transit Expansion Study (RTES) has recommended that, as a priority, the rapid transit service be extended to the east into downtown and to the south to the new growth area of Riverside South, the Ottawa Macdonald Cartier International Airport and eventually across the Rideau River to the Barrhaven area.

The use of the rail corridor (for the Pilot Project) from Bayview to Leitrim and the maintenance facility at Walkley Yards is governed by a lease agreement between the City and Canadian Pacific Rail. The City is in the process of acquiring this corridor from CP Rail.

3.0 Light Rail Transit Characteristics

The purpose of this chapter is to provide background about Light Rail Transit by explaining what it is, outlining the types of LRT systems that exist and discussing the types of vehicles being developed and used for LRT services.

3.1 What Is Light Rail Transit?

Light Rail Transit (LRT) is a system of passenger transit that typically operates in urban settings. LRT usually runs at street-level in mixed vehicular and pedestrian traffic. Although grade separations are possible, it is assumed that the Ottawa system will be at-grade. LRT is typically propelled by overhead electrical wires although there are some systems that use diesel or electricity from a third rail as a power source. Some familiar terms that are commonly used to describe LRT are streetcar, tramway, and trolley.

LRT systems consist of relatively lightweight, steel-wheeled vehicles that run on steel rails. Train consists can be made up of single cars, or multiple cars coupled into short trains. The length of a train is affected by alignment constraints, street block lengths, and capacity demand.

There are several right-of-way (ROW) possibilities for LRT systems:

- An exclusive ROW is isolated from other traffic by either a grade separation or an at-grade exclusive lane separate from vehicular traffic with signalized crossings giving priority to public transit.
- A shared ROW separates LRT from other traffic with street-level transit lanes (such as on a median) that are designated solely for LRT use by a curb-type barrier or paint. Crossings may be handled with priority transit signals, or regular traffic signals.
- A common ROW allows LRT systems to operate in mixed vehicular and pedestrian traffic, and they are subject to street-level speeds and congestion. Crossings are usually handled by regular traffic signals.

The use of steel rails in LRT systems frees the driver from having to steer through traffic. Light Rail Vehicles (LRV's) are usually boarded at street-level with the aid of steps, ramps, or raised platforms depending on the floor height of the vehicle. Electrically propelled LRT systems are often chosen because they minimize air pollution in the corridor compared to other transit options.

3.2 Types of LRT Systems

3.2.1 Electric Light Rail Transit

The most common type of Light Rail Transit is the Electric LRT which runs primarily on street-level tracks in shared ROW's. The vehicles draw electric power from an overhead contact system called a catenary. Historic streetcars operate using this trolley technology, which has been modernized over the years.

Electric LRT vehicles are designed to function in urban environments, and are capable of providing suburban service on shared, exclusive, or semi-exclusive ROW's. Most are articulated which allows them to turn tight corners on city streets. The lightweight vehicles allow the trains to climb steeper grades than systems designed to be shared with traditional heavy rail traffic. Most are double-ended with doors on both sides which provide quicker boarding and exiting times, and negates the need for a loop at the end of a line. The current trend in modern electric LRT vehicles is to provide low floors for easier access and less obtrusive platforms.

The Houston METRORail, Minneapolis Hiawatha Line, Portland MAX, San Jose Light Rail, and Calgary Light Rail are examples of Electric Light Rail Systems.

3.2.2 Diesel Multiple Units (DMUs)

Diesel powered Light Rail Vehicles (DMUs) have recently been reintroduced to North America. Unlike traditional heavy freight and commuter rail cars hauled by one or more locomotives, DMU passenger vehicles are self-propelled and contain their own diesel engine. As far back as 1949 the Budd Company manufactured early DMUs known as RDCs or Rail Diesel Cars but ceased production in 1962. Only Bombardier and Colorado Railcar currently offer DMUs for the North American market, and their vehicles are in operation in Ottawa, Florida, and New Jersey.

DMU's were developed for longer distance commuter rail service and can run on separate railway right of ways or in mixed freight traffic. In order to operate on freight lines in North America, the DMU must be fully US Federal Railway Administration (FRA) compliant to ensure crash safety. Because the propulsion equipment is located in the undercarriage of the vehicle, DMU floor heights are generally higher than electric LRV's and the minimum turning radii are larger.

The Ottawa O-Train uses Bombardier's Talent DMU on an existing freight line. It is an articulated vehicle that must operate at different times than regular freight traffic since it is not FRA compliant. It was originally designed to operate on European commuter rail lines and has been slightly modified for the Ottawa operation.

The New Jersey Transit River Line also uses a Bombardier articulated DMU (model GTW 2/6). This is the first diesel light rail system operating on an existing freight corridor in the United States. These trains run on street, on light rail dedicated tracks, and on freight mainline tracks. Like the Talent, this vehicle must operate at different times than the freight trains for safety reasons.

Colorado Railcar is the only manufacturer to produce a Federal Railway Administration (FRA) compliant DMU, which is now in service in Southern Florida. This vehicle acts as both a self-propelled passenger railcar and a locomotive that can pull two coaches. It is not articulated and has less flexibility to operate in challenging urban alignments compared to the Talent and River Line DMU's. It is fully capable of operating on freight corridors, and is considered a "commuter" vehicle more than a light rail vehicle. For the purpose of considering all DMU options, it has been included in this report.

3.3 Examples of Recent LRT Systems

There are approximately 25 Light Rail Transit Systems operating in North America today, with nearly double that amount planned for future systems. While each of these systems could be discussed in great length, this section is intended to provide only a few examples of where Light Rail systems have been implemented in recent years.

3.3.1 Houston, Texas

The Houston Metropolitan Transit Authority opened Houston's first light rail line (METRORail) in January 2004. This "starter" line runs 7.5 miles (12.1 km) from the University of Houston's downtown campus linking downtown, midtown, the Museum District and the sprawling mile long complex of the Texas Medical Centre. The service is operated 19 hours a day using 18 Siemens S370 LRT vehicles. The vehicle has a 70% low floor configuration and the car type is nicknamed "Avanto".

Service is provided 19 hours a day. Trains currently operate on 6-minute headway from 4:30 a.m. to 7:30 p.m. with longer headways in the evenings and on weekends. Normal service is with single-car trains, but the LRVs can be coupled in 2-car sets and were used that way on Opening Day and on Super Bowl Sunday in 2004.

3.3.2 Minneapolis, MN

Metro Transit opened the initial phase of its Hiawatha Line in June, 2004 with the remaining 4 miles opened in December, 2004. This brand new 12-mile Light Rail System connects downtown Minneapolis to the Minneapolis/St. Paul Airport and the Mall of America in Bloomington. It runs on an exclusive ROW with two tunnels and two bridges. The system includes 17 stations and two park-and-ride lots. 14 of these stations are fed by bus service. The projected ridership is 19,300 passengers per weekday in 2005, and 24,600 per weekday by 2020. 24 low-floor LRV's were ordered from Bombardier's "Flexity Swift" line of vehicles for approximately $3 million each. The total cost for this project was $715.3 million ($US).

3.3.3 Tacoma, WA

Sound Transit opened the 1.6 mile Tacoma Link Light Rail in August, 2003. This is a single-track service running on a shared ROW in mixed traffic with transit priority signals. It takes only eight (8) minutes to ride the length of the corridor from the Theatre District to the Tacoma Dome Station. There are five (5) stations along the corridor and one park-and-ride lot. Three (3) low-floor Model 10-T LRV's were ordered from Skoda in the Czech Republic for a total cost of $9 million including spare parts, taxes, and shipping.

3.3.4 Charlotte, NC

North Carolina's first Light Rail, the South Corridor Light Rail Project in Charlotte, is scheduled to begin service in the fall of 2006. The Charlotte Area Transit System (CATS) and the Metropolitan Transit Commission (MTC) chose Electric Light Rail Vehicles over bus rapid transit and Diesel Multiple Units. Groundbreaking for construction took place in September 2004.

The project is approximately 10 miles in length from uptown Charlotte to Interstate 485. It will run on an exclusive ROW on the Norfolk Southern ROW with the northernmost two miles on shared tracks with the Charlotte Trolley. The system will include 15 stations, with park-and-ride lots at seven (7) of them. Projected ridership is 17,000 passengers per day. Capital costs for the project are estimated at US$398.7 million. This includes US$52.5 million for 16 low-floor Siemens S70 LRV's (including spare parts and system support). There is an option for ordering an additional 25 vehicles in the future. Houston and San Diego have also recently purchased Siemens S70 vehicles for their Light Rail Systems.

3.3.5 San Jose, CA

The Santa Clara Valley Transportation Authority (VTA) has three light rail projects underway. Kinkisharyo Inc. is supplying 70 new low-floor light rail vehicles to serve the entire VTA Light Rail system. Delivery was complete in early 2004 for a total cost of $200 million.

The Tasman East Light Rail and the Capitol Light Rail projects are extensions of the existing VTA Light Rail into Milpitas and Eastern San Jose. They will connect with bus service and the future San Francisco Bay Area Rapid Transit (BART) extension. The extension is 8.2 miles in length and runs from Baypointe Transfer Station to Alum Rock Avenue. The system will include 11 new stations.

The first 1.9 miles of the Tasman East corridor was completed in May of 2001. The second 3.0-mile phase of Tasman East includes a 7,200 ft elevated bridge and was completed in the summer of 2004. The Tasman portion of the project is expected to cost $275.1 million ($US).

The Capitol Light Rail portion of the project is a 3.3-mile extension of the Tasman line that runs along the median of Capitol Avenue in a shared ROW. Construction was completed in the summer of 2004. The project cost for the Capitol extension is $159.8 million ($US).

The third extension to the existing VTA Light Rail system is the Vasona Light Rail Extension. This is a 6.8-mile extension between Woz Way in downtown San Jose to Los Gatos. The line will operate mainly on the Union Pacific Railroad right-of-way (exclusive), with a portion in a tunnel alignment. Phase 1 construction began in March 2001 and the entire system should be operating by January 2006 with 11 new stations. The capital cost for the Vasona project is $375.8 million ($US).

3.3.6 River Line, NJ

The New Jersey Transit Corporation's River Line is the first diesel electric light rail system operating on an existing freight corridor in the United States. This 34-mile line runs from Camden to Trenton, NJ on the Delaware River's Route I30 corridor, as well as on street tracks and dedicated light rail mainline tracks. 20 stations have been built for this line, which opened in March, 2004. Bombardier supplied 20 Diesel Multiple Unit LRV's for the River Line.

3.3.7 U.K. Systems

In addition to the recent North American examples, a number of LRT systems have opened in England since 1980. These are summarized in Table 3.1.

Table 3.1

System	Year Opened	Route Length (KM)	Annual Ridership (2002-03, millions)	Total Capital Costs (at time of completion) (£ million)
Tyne & Wear Metro (with Airport and Sunderland extensions in 1991 & 2002 respectively)	1980-84	77	37	284 (1980-84) 98 (2002)
Docklands Light Railway (with Bank, Beckton and Lewisham extensions in 1991, 1994 & 1999 respectively)	1987	27	46	77 (1987) 282 (1991) 258 (1994) 220 (1999)
Manchester Metrolink (with Eccles extension in 2000)	1992	39	19	145 (1992) 160 (2000)
Sheffield Supertram	1994-95	29	12	241
Midland Metro (Birmingham)	1999	21	5	145
Croydon Tramlink	2000	28	19	200
Nottingham Express Transit	2004	14	N/A	180

Source: "Improving Public Transport in England Through Light Rail" Comptroller and Auditor General, National Audit Office, United Kingdom Government, April 2004.

Additional information about some of these systems is provided in the following paragraphs.

Midland Metro (Birmingham)

The Midland Metro route is 21 km long, with 2 km of street running track and a shared alignment for the rest of the length. The system is fully electrified with 750 volt DC power supplied through overhead cables along the entire length of the route. There are 23 stations along the route that are designed to serve both local communities and commuter traffic. Each of the 16 trams operating on the route is fully accessible with dedicated space for two wheelchair customers. Each tram has 56 seats and can carry up to 208 passengers (56 seated, 152 standing).

Nottingham Express Transit (NET)

NET Line 1 began operation in March of 2004 with a 14 km line running north from the city centre. The line includes 23 stations that are designed to accommodate the development of bus and minibus feeder services. Ridership for Line 1 is forecast at 11 million per year. Trams are electrically powered via a conventional 750-volt overhead contact system. There are 15 Bombardier Incentro trams (also used in Nantes, France) that are 32 m long and can operate at speed up to 80 km per hour. Two extensions to the NET are already in development, one of 7.6 km to the south and another of 9.8 km to the west.

Manchester Metrolink

The Metrolink network covers 38 km. around Greater Manchester from the north, through the city centre to the south and the west. It has a fleet of 32 trams and serves 36 station stops, including 18 former British Rail stations, 15 new open plan stops and three shared mainline stations. The use of the former British Rail stations and the shared mainline stations requires that the trams use high platforms, with the floors 915 mm above ground.

3.3.8 Europe

Examples of some modern European LRT systems are summarized below.

Barcelona

In 2004 Barcelona opened two technically similar, LRT tramway systems mostly utilizing existing major arterial road right-of-way. With a total line mileage of 29.3 km (19.2 miles), Barcelona's two LRT startup projects cost a combined total of Eur 451 – amounting to about $19 million/km, or $30 million/mile.

Trambaix – Opened on 3 April 2004, this system is located in the southwestern part of Barcelona, linking the university area with the Baix Llobregat suburbs on the southern edge of the city. Total line length is 15.8 km (9.8 mi), with 28 station-stops. Capital cost was Eur 246, or about US$320 million. With 3 route permutations, this system is expected to carry about 7.6 million rider-trips annually (24,500 trips per day). Schedule speeds for the three route services average about 19 kph, or 12 mph.

Trambesos – Opened on 8 May 2004, this system is located in the northeastern part of Barcelona, in the Badalona and Sant Adria de Besos districts of the urban area, serving the environs near the 1992 Olympic Village. Total line length is 13.5 km (8.4 mi), with 27 station-stops. Capital cost was Eur 205, or about US$266 million. There are two route permutations on this line, with schedule speeds averaging about 20-21 kph (13 mph).

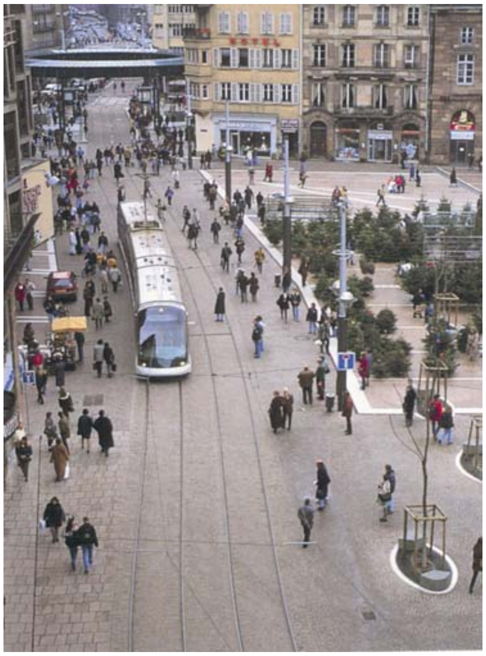
Nantes

In 2000 Nantes opened the extensions to two LRT lines (10 km at a cost of FFr 1.3 billion). Nantes, which has the longest light rail network in France, has a fleet of pre-Citadis Alstom vehicles, but in April this year decided to buy 23 of the Adtranz modular LRVs under the name Incentro. These five-section articulated vehicles are 36.4 m long and 2.4 m wide and run on three bogies. At 33 tonnes it lays claim to being the lightest LRV in the world for its length. The vehicles, type AT6/5L, can carry 259 passengers, 76 of them seated.

In order to achieve the lowest possible floor level, electrical equipment was switched to the roof area. Narrower seats and the removal of interior steps have created more circulation and boarding room in order to reduce station dwell time.

Strasbourg

The first section of line opened in November 1994, and has since grown to 47 stations along a 25 km network. Various versions of the Eurotram light rail vehicle are used throughout the system. Some of the fleet (36 units) is 33 m long with a capacity of 285 passengers of which 66 are seated, while the remaining 17 units are 43 m long with a capacity of 370 passengers, of which 92 are seated. All of the vehicles include the latest automated train protection equipment, and the driver has full control of all equipment from the cab. A fully automated interlocking signaling system allows for the operation of short headways, especially on the slower-speed sections through the city centre.



3.4 Light Rail Vehicles

Terms for different types of rail vehicles are loosely defined in the transportation industry. For the purpose of this report, Electric Light Rail Vehicle (LRV) and Diesel Multiple Unit (DMU) from the previously described systems will be used when referring to the vehicles in consideration for the North-South Corridor.

Most vehicle manufacturers offer a base model of each of their vehicles with basic specifications to give an example of what can be produced. In reality, their vehicles are rarely manufactured as stated in the specifications. Each transit authority has different needs and constraints, and most manufacturers will tailor their vehicles to suit the demands of a particular system. Dimensions, power, and seating configuration are examples of things that can be modified if needed to meet various design parameters.

Following is a description of the various physical and performance characteristics that should be considered when selecting the appropriate vehicle for a system. Each attribute is an important component of the vehicle's overall suitability for a system. The most important categories are discussed below with an explanation of their significance. The actual range of data values for both Electric LRV's and DMU's are given following the description of General Characteristics.

Pictures and details of some of these LRT and DMU vehicles are provided in Appendix A. Additional detail and specifications for sample rail vehicles is provided in Appendix B.

GENERAL LRT CHARACTERISTICS

Power Supply

Light Rail Vehicles can be propelled by an overhead electrical catenary wire or a diesel engine. The advantage of an overhead contact system is that it causes less air pollution, is quieter, and there is less bulky propulsion equipment to fit within the car body allowing more flexibility for low floors and articulation. The advantage of a diesel-powered vehicle is that there is no need to construct an expensive and obtrusive overhead wiring system. Without the overhead wires, the vehicles can easily transfer to commuter or freight rail lines.

Speed and Acceleration

The speed at which an LRV can travel is a function of its power, the type of ROW, and the spacing between stops. A street-level system in mixed traffic will have varying speeds depending on the speed of the other vehicular traffic. A system on an exclusive or separate ROW will be able to travel faster since it will encounter fewer crossings, and have fewer obstacles to slow it down.

Given a typical acceleration, the spacing of station stops dictates the maximum speed that an LRV will obtain, which in turn dictates the maximum speed required when selecting a vehicle. Closely spaced stops in urban settings will require the vehicles to accelerate quickly for efficient service, but the maximum speed reached will be low since it will have to stop again quickly. When there are longer runs between stations, the vehicles will have time to achieve higher speeds. Vehicles that require high speeds tend to have lower acceleration rates, and vice versa.

The maximum speed and acceleration values are the vehicle's maximum safe operational values. The speed values range from 65 km/h to 105 km/h, and acceleration ranges from 0.8 m/s^2 to 1.41 m/s^2.

Grade
LRV's operating on city streets must be able to handle the steep grades in an urban landscape. Vehicles with limited grade capabilities restrict the alignments that can be selected.

Turning Radius
Further to the grade requirements, LRV's in urban settings must be able to navigate around tight corners by having a small turning radius. Most new electric LRVs can navigate at 25 m radius curve turning from one downtown street to another while DMU vehicles generally require 90 m or more making them at times unusable in a downtown environment.

Floor Height
Floor height is one of the most important considerations when choosing an LRV. In order to provide accessible vehicles for people who are unable to use stairs, modern systems have been designed to match the platform boarding level with the level of the vehicle floor. Most vehicles require some type of platform for accessibility reasons.

When a low-floor vehicle is used, the platform level can be close to curb height, or the car may have a retractable ramp to street level. This is desirable when the public does not want a large platform obstructing views, or when the existing street right-of-way does not allow space for a large platform. Low-floor vehicles have roof-mounted equipment instead of in the undercarriage.

High-floor vehicles must have either a high platform for level boarding, or interior steps to access the seating area. The current trend is to avoid the need for steps in order to increase accessibility. High floors are mostly found in older vehicles such as the Toronto streetcars. Some vehicles have a combined low- and high-floor configuration. A 70% low-floor vehicle means that 70% of the floor area is at the low-floor level, while the remaining floor is raised. Most vehicles have a raised floor over the wheels at both the front and rear of the car. Seating in these high-floor areas is usually accessible by interior steps.

Dimensions
The length, width, and height of an LRV must be considered in relation to the available ROW, overhead and side clearances, and different platform options. Vehicles with roof-mounted equipment will be taller. The length of a train consist must fit within the constraints of the LRT network to avoid blocking intersections, exceeding platform lengths, etc.

Passenger Capacity
The required passenger capacity of a vehicle depends on the demand along the corridor as well as the projected population growth. Larger cars that can hold more passengers are best for main corridors that have the highest demand. In city centres, smaller cars with less capacity are considered better for aesthetic reasons. Most vehicles can be coupled into short trains to increase capacity should the need arise. Changing the seating configuration of a vehicle can also increase capacity, as fewer seats will allow more standing room and a higher capacity.

Visibility
A low cab and good peripheral vision are necessary for LRV drivers to see other traffic when operating on a shared ROW. The visibility rankings in Appendix A are subjective and were chosen based on height of cab and peripheral vision. A "good" ranking means the driver seat is low to the ground and has large side windows. A "fair" ranking means only one of these conditions exists, while a "poor" ranking indicates a high driver seat with limited side vision.

3.4.1 Electric LRV's

The physical and performance characteristics specific to Electric Light Rail Vehicles are discussed below. This information provides a range of vehicle specifications that can be used when developing design parameters for an LRT system.

Power Supply
Electric LRV's are powered by an overhead catenary wire that supplies a particular voltage. The typical range is from 600 Vdc to 1500 Vdc, given as either 600, 650, 750, or 1500 Vdc. 750 Vdc is the most common voltage in both North America and Europe, with 1500 Vdc being the least common in North America.

Speed and Acceleration
The range of maximum operational speed for electric LRV's is anywhere from 65 km/h to 105 km/h. The most common speed is 88.5 km/h; therefore, it is reasonable to expect to find a vehicle that is capable of speeds between 85 km/h and 105 km/h. The Kinki Sharyo LRV in Dallas, Siemens S70 in Houston and Charlotte, Siemens SD-160 in Salt Lake City, and Siemens SD-460 in St. Louis are all capable of speeds up to 105 km/h.

Rates of acceleration range from 0.8 m/s^2 to 1.41 m/s^2. The typical value in North America is 1.34 m/s^2, which is found in all of the Kinki Sharyo vehicles and most Siemens vehicles. The LRV with the best acceleration rate is the Ansaldo Breda LRV in San Francisco, although this vehicle's maximum speed is only 80 km/h.

Grade
The maximum grade on which an electric LRV can operate is approximately between 4% and 9%. Vehicles manufactured for North America are typically capable of handling a 6% or 7% grade. The Ansaldo Breda vehicles in Boston and San Francisco have the highest grade in this study at 9%. Some manufacturers did not make their grade capabilities available for this study.

Turning Radius
Minimum turning radii typically range from 13 m to 30 m. Articulation helps the vehicles turn around tight corners. North American values are usually around 25 m, with the Ansaldo Breda vehicles in Boston and San Francisco as low as 13 m and 14 m. Some manufacturers did not make their turning radii available for this study.

Floor Height
Low-floor heights are usually between 0.3 m and 0.4 m, with high floors anywhere between 0.6 m and 1.15 m. The most common low-floor height is 0.35 m (14 inches). As stated earlier, most low-floor vehicles have a high-floor portion at either end, meaning there are numerous floor height combinations.

Dimensions
The dimensions of an LRV can vary depending on seating configuration, door arrangement, and other factors. Most models are versatile in their dimensions, depending on the constraints of the system they are operating on. Typical ranges in height are 3.19 m to 3.89 m. Width values range from 2.3 m to 2.74 m and length can be from 20 m to 40 m. North American vehicles are between 20 m and 30 m in length.

Passenger Capacity
The number of seats in an LRV depends on the size of the vehicle, how the seats are configured, the number of wheelchair spaces, and how much standing room is to be left available. Smaller vehicles tend to have a lower number of seats, but this can be changed by adjusting some of the above-mentioned factors.

The amount of standing room also varies, and depends on how crush-load is measured and what the safety standards are. Most vehicles can be custom-made to suit the capacity needs of a system, as long as they are within their dimension limits.

The seating capacity for electric LRV's in this study ranges from 30 to 96 seats. Most North American vehicles are in the range of 55 to 75 seated passengers per vehicle, with the CAF Sacramento LRV having the highest number at 88. LRV's can hold a total of up to 300 passengers, with typical North American capacities between 150 and 250.

Visibility
Electric LRV's tend to have good visibility since they are designed to operate at street-level in mixed traffic. The driver must be able to see other vehicles and pedestrians; therefore, the driver seat is low to the ground and has side windows for peripheral vision. The Siemens S70 is an example of an LRV with excellent visibility.

3.4.2 Diesel Multiple Units

The physical and performance characteristics specific to Diesel Multiple Units are discussed below. Since only three (3) DMU models operate in North America, there is a limited range of experience. DMU vehicles have different characteristic than Electric LRV's because of the engine configuration and their development as longer distance commuter rail vehicles intended to operate on existing rail lines.

Power Supply
The Bombardier Talent has a diesel-mechanical traction system. The Bombardier River Line DMU has a diesel-electric system, and the Colorado Railcar DMU has a diesel engine with a hydrodynamic transmission.

Speed and Acceleration
DMU's are generally designed for higher speeds than electric LRV's, but have lower acceleration rates. The River Line DMU can operate at 96 km/h, the Talent at 120 km/h, and the Colorado Railcar at 145 km/h. Acceleration is often sacrificed for speed, as the fastest vehicles tend to have the slowest acceleration rates. The River Line DMU accelerates at 0.90 m/s^2, the Talent at 0.83 m/s^2, and the Colorado Railcar at 0.53 m/s^2.

Grade
Due to the large size and weight of DMU's, they cannot handle grades as steep as electric LRV's can. The River Line DMU is capable of operating on a 6% grade, while the Talent can handle only 3.5% and the Colorado Railcar 3.2%.

Turning Radius
As previously mentioned, the engine and transmission configurations of DMU's make it difficult for them to navigate around tight corners. Diesel-electric systems are more flexible since the engine can be placed away from the wheels. The Talent can turn a radius of 90 m, while the Colorado Railcar has a minimum turning radius of 76 m. The River Line DMU has the shortest turning radius capability with a minimum turning radius of 40 m.

Floor Height
DMU's have higher floors than electric LRV's because the traction system must be placed in the floor of the car, except in the case of a diesel-electric system where the engine can be placed in a more convenient

location. The River Line DMU's low-floor section is 0.584 m high, and the high-floor section is 1.0 m above top of rail. The Talent and Colorado Railcar have floor heights of 0.59 m and 1.30 m above top of rail, respectively.

Dimensions

The River Line DMU, Talent, and Colorado Railcar have heights of 3.91 m, 3.86 m, and 4.54 m, widths of 3.00 m, 2.93 m, and 3.05 m, and lengths of 31.24 m, 48.36 m, and 25.91 m respectively.

Passenger Capacity

The large DMU vehicles have more space for seats that some electric LRV's. Seating capacity can always be altered depending on the specifications of the client. The River Line DMU holds 90 seated passengers with 94 standing, the Talent holds 135 seats with 150 standing, and the Colorado Railcar holds 92 seats with 162 standing. Since these vehicles are used for some commuter transit, it is reasonable to include more seats and less standing area than would be installed in a vehicle operating only on city streets.

Visibility

DMU's do not have good visibility because they operate mainly on separate rail ROW's, or on mainlines shared with freight traffic where the driver does not have to watch for cross-traffic. The driver seat can be on a high floor with little peripheral vision. Of the three (3) DMU's operating in North America, Statler/ Bombardier's River Line DMU has the best visibility, with large side windows and a relatively low floor compared to the other vehicles.

4.0 Bus Rapid Transit Characteristics

The purpose of this chapter is to provide background about Bus Rapid Transit by explaining what it is, outlining key BRT system characteristics, describing BRT systems that currently exist, and discussing the types of vehicles being developed and used for BRT services. Some of the material in this chapter is drawn from the report "Bus Rapid Transit – A Canadian Industry Perspective", published by the Canadian Urban Transit Association in February 2004.

4.1 What is Bus Rapid Transit?

A unique, overall definition of BRT that encompasses all of the necessary elements, and is fully applicable in the Canadian context is:

- Bus Rapid Transit is a rubber-tired rapid transit service that combines stations, vehicles, running ways, a flexible operating plan, and technology into a high quality, customer focused service that is frequent, fast, reliable, comfortable and cost efficient.

The key characteristics that are different from LRT systems are running ways and operating plans. These are described below.

4.1.1 Running Ways

"Running Ways" is the general term used to describe the travel lanes that BRT services operate on. There are three general types of BRT running ways, each of which have various configurations:

Brisbane Busway

1. Exclusive Busways: This category describes limited access running ways that are generally not used by any other traffic or mode of transportation. The busways will typically be located in separate rights-of way such as railway corridors (existing or abandoned), utility corridors (such as hydro corridors), and in the medians or boulevards of existing roadways. Types of facilities in this category can include grade-separated busways (intersections with general traffic streets are avoided by using bridges over or under the crossing street), and at-grade busways that cross streets at signalized intersections. Some transit malls in urban or suburban business districts could be considered as at-grade busways. Some or all traffic signals may provide priority to BRT vehicles in order to minimize delay at cross streets.

Ottawa Bus Lanes

2. Dedicated Lanes. These are exclusive transit or high occupancy vehicle (HOV) lanes that are located on existing roadways, but are separated from the regular road lanes in some way. Use of the dedicated lanes is restricted to buses and BRT vehicles in the case of transit lanes, and to buses, BRT vehicles, vanpools and carpools in the case of HOV lanes. Traffic signal priority for BRT vehicles and other buses can be used to maintain schedules and service intervals.

Vancouver, B.C.

3. Mixed Traffic. It is possible for BRT services to operate in mixed traffic in cases where dedicated facilities are not required to guarantee reliable operation. Any occasional delay points for the BRT services can be addressed through site specific transit priority measures such as queue jump lanes and/or some form of traffic signal priority.

It is possible for BRT services to combine use of different types of running ways. For example, a service may operate on a bus lane in a suburban area before joining an exclusive busway to travel further into town. The busway may lead to a lightly used roadway where the BRT service continues without delay in mixed traffic before rejoining an exclusive busway to complete the journey to the central area.

4.1.2 Operating Plan

An operating plan for a BRT facility can take advantage of a variety of service alternatives:

- All Stops Route(s) – Like Ottawa's route 95,this route operates just like a rail service, running over the full length of a Busway and stopping at each station where it services passengers arriving and departing the station. The route may be extended beyond the Busway in order to serve key travel demand generators. The all stops route service frequency will be high during most time periods (at least every 5 minutes during peak periods and 10 minutes during the midday). This type of route typically requires even higher frequency service along busier sections close to the city centre, and the use of high capacity vehicles such as articulated buses.

Figure 4.1 - Ottawa Transitway System Map

- Peak Direction Express/Limited Stop Service – A key busway feature is the ability to offer a high frequency no-transfer service to a high proportion of trips. This is achieved through the operation of a network of one-way, high frequency express/limited stop services. In the morning peak period, for example, buses pick up passengers in residential areas away from the busway, travel on the local street system to the busway, and then operate on the busway in an express or limited-stop mode, depending upon the demand levels and trip patterns. The intermediate busway stations allow customers to directly access developments next to the stations and to transfer to the all stops and counter peak direction express/limited stop services for travel to other locations in the corridor. In the afternoon peak period, the one-way service is provided in reverse.

- Counter Peak Direction Express/Limited Stop Service – The all stops service serves corridor destinations, but to reduce the need to transfer to major destinations away from a busway, a network of counter peak direction express/limited stop routes can be operated. These routes operate during the peak period, typically starting a busway station close to the city centre in the morning, travel along the busway, then operate on the local street system in order to access a commercial area, business park, hospital, educational centre, or a series of the facilities located near each other. Because these routes operate in the counter peak direction, they can be provided at a low marginal cost by using bus trips that would otherwise be the dead head (out of service) links for the one-way peak direction express services.

- Local Arterial/Feeder Services – Arterial bus services will always be operated in conjunction with BRT services. To take maximum advantage of BRT, their routes may need to be modified to reflect the presence of a facility. These modifications could include:
  - Route diversions to ensure that each route intersects the busway in at least one location where passengers can transfer conveniently at a station;
  - The elimination of the route sections where arterial bus service can be replaced by walk-in access to the busway;
  - Route diversions where the arterial route may actually use a section of busway; and,
  - Timing changes to provide a 'pulse' operation at major transfer locations (particularly late at night when service frequencies may be low).

4.2 Examples of BRT Systems

4.2.1 Ottawa, Canada

The Transitway opened in 1983 and consists of a 60-km system that includes 26 km of bus-only roadway, with most of the remaining distance on reserved freeway or arterial lanes. The system feeds into downtown Ottawa and transitions to surface street operations in the downtown in transit only bus lanes. The "outside-in" approach to building the Transitway has meant that in the central city, operations are still accommodated on city streets, which, because of exclusive bus lanes, provide capacities of 10,000 passengers and approximately 200 buses per hour in each direction.

4.2.2 Pittsburgh, USA

Pittsburgh has been using dedicated busways for over 25 years. The city has 18.5 miles of dedicated bus lanes on three routes. The West Busway opened in 2000. This five-mile busway, constructed in an abandoned rail right-of-way, connects the City of Pittsburgh and Pittsburgh International Airport. The facility varies in width from two to four lanes, providing passing opportunities at the busway's six stations. The exclusive Busway extends from Carnegie to east of the Sheraden Station, at which point, buses merge with traffic on West Carson Street via an exclusive bus ramp and proceed to downtown Pittsburgh via West Carson Street. Synchronized traffic signals are provided along West Carson Street. In June 2003, a new 2.3 mile, four-station extension was opened. Although Pittsburgh's busway system is generally considered successful, it does not have level-boarding, advance fare collection and rail-like stations, and does not make extensive use of ITS technologies.

Pittsburgh Busway – West Busway

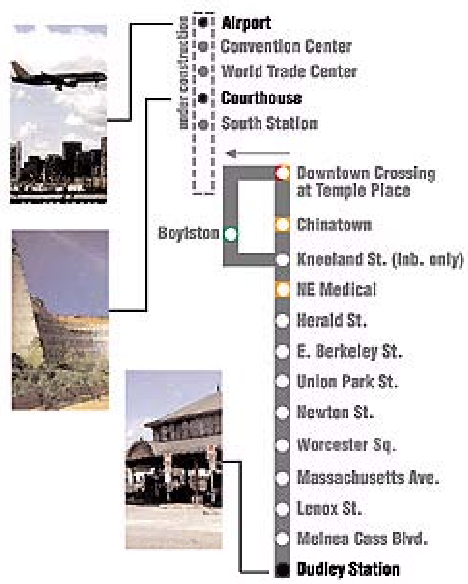
Pittsburgh Busway – Station

4.2.3 Boston, USA

The Silver Line will connect downtown Boston to Logan Airport with dedicated bus lanes and bus only underground tunnels. Upon completion in 2010, the facility is expected to carry 60,000 passengers a day. The Silver Line service is being introduced in stages as construction on its three major sections is completed. The section of the Silver Line route between Dudley Square and Downtown became operational 2002. The leg between South Station and Logan Airport via the South Boston Waterfront will begin service in Spring 2004. The final section -- linking Downtown and South Station -- is slated for completion by 2010.

Service will be provided by 60-foot Neoplan low floor, climate-controlled, dual-mode buses. Each Silver Line station will have real-time passenger information and will be designed with rider comfort, convenience and safety in mind.

Boston Silver Line - System Map



4.2.4 Curitiba, Brazil

Curitiba's BRT system is the most extensive in the world with a fleet of 1,100 buses. 1.3 million passengers per day ride the system, equivalent to 55% of the total transportation demand in the city. Express buses operate on dedicated busways, while *rapid buses* operate on arterials. *Interdistrict* buses allow passengers to travel between city sectors and feeder buses mix with all other traffic on city streets. "Fare-less" boarding also improves the speed of the system.

Curitiba BRT – fare collection/boarding tube station

Stations on the main lines are located in the median at an average distance of 500 meters. The elevated platforms, at 1.5 meters high, are level with the bus floor. Fare collection is off-board. The service uses high-capacity, articulated vehicles powered by low-emission power plants.

4.2.5 Brisbane, Australia

Brisbane South East Busway station

Brisbane's new South East Busway, opened in 2000 – 2001, is one of the most technologically advanced Bus Rapid Transit systems in the world. It represents the "state-of-the-art" in Busway design, infrastructure and operations management. The South East Busway and various other Brisbane busway initiatives are modeled on the Ottawa (Canada) Transitway system. The system places significant emphasis on passenger amenities both in the stations, on the vehicle and in the level of information services. The operation uses modern low floor, air-conditioned conventional bus transit vehicles operating at high frequency within a completely separate right-of-way.

4.3 BRT Vehicles

Conventional transit vehicles are used, and will continue to be used on BRT systems throughout the world. However, a new breed of transit vehicle is emerging that combines vehicle characteristics that respond to the specific demands of the BRT service concept. The vehicle dimensions, material and performance specifications and geometric operating criteria are generally similar to conventional bus technology and governed by federal and provincial vehicle safety standards, applicable design codes, public vehicle and highway traffic act regulations. However, there is a perception that the BRT vehicles must incorporate advanced aesthetics and styling to clearly distinguish the system from the conventional bus system and to provide greater emphasis on passenger comfort. This direction is evident in the vehicle concepts being put forward by the various manufacturers. The vehicle designs feature distinctive styling with sleek exteriors, wrap treatments to cover the structural body components, and large windows. The vehicles combine performance and operational efficiency with a greater emphasis on passenger comfort. BRT vehicles combine many of the desirable features of light rail technology with a generally lower overall cost and greater flexibility in operations compared with that offered by rubber-tired vehicles. Features of BRT focused vehicles include the following:

- **Low floors:** Contribute to fast and convenient boarding by eliminating steps, providing greater accessibility for people with disabilities, and when combined with raised platforms, can provide for level boarding. Low floor vehicles can be more difficult to navigate in the vicinity of platforms and guidance systems can be used for precision docking.
- **Multiple Wide Doors:** Allow for fast boarding of vehicles and can significantly reduce dwell time. Increasing the number of doors from two to three can potentially increase the passenger handling capability at stops by 50 percent and can improve distribution of passengers within the vehicle. Multiple door configurations are best used in conjunction with automated or off-vehicle fare collection or pay-on-exit type fare schemes. Two-sided BRT vehicle designs can support loading on both sides and provide greater flexibility in terms of stop arrangements.
- **Internal Circulation:** BRT vehicles are characterized by wide aisles and efficient interior design that allow greater passenger comfort through reduced crowding, facilitate fast boardings and alighting, and allow for optimized vehicle loads by improving the distribution of passengers in the vehicle.
- **Reduced Environmental Impact:** Alternative fuels and reductions in noise and air pollution contribute to a progressive image of the service, and to hence passenger comfort. Newer propulsion system options include compressed natural gas (CNG), hybrid electric-diesel buses, and next generation diesel.
- **Distinctive Vehicle Design** combined with branding and unique vehicle livery serve as a significant marketing element and can be a visual reminder to the public that the quality of service is beyond regular bus service. In addition to incorporating vehicle features from light rail vehicles, such as multiple door configurations, design cues are also taken from light rail vehicles to visually communicate the higher quality of service that these vehicles are typically associated with.

4.3.1 Vehicle Products (Existing & Under Development)

Bus manufacturers offering low-floor bus designs for the North American market include: Gillig, Neoplan USA, New Flyer Industries, North American Bus Industries, Nova Bus, and Orion Bus Industries. Of the three Canadian vehicle manufacturers, New Flyer is the first to offer a vehicle that incorporates BRT vehicle design characteristics. Nova Bus and Orion are evaluating market interest and contemplating BRT type vehicle design features.

Pictures and details of some of these vehicles are provided in Appendix C.

5.0 Rail or Bus in the Study Corridor

5.1 Comparing LRT and BRT in the North-South Study Corridor

For every proposed major rapid transit initiative there is almost always a debate over the appropriate transit mode to use, and in particular when it comes to choosing between bus and rail. There is no one answer to that question because it depends on the corridor, the ridership and the political will of the local community. There are over 400 Light Rail installations worldwide and a significant number of Bus Rapid Transit installations.

In order to provide a comparison on an "apples to apples" basis, theoretical LRT and BRT systems were developed to serve the north-south study corridor from Barrhaven in the southwest to the Rideau/Congress centres in downtown Ottawa. The system scenarios were developed based on the longer term (2021) scenario.

5.1.1 Forecast Ridership in the Study Corridor

A detailed ridership study of the proposed O-Train system expansions was initiated in early 2004 and has recently been completed. This study was carried out to support the North-South Corridor Environmental Assessment study and initial and long term operations planning in the corridor. The ridership estimates focused on the AM peak hour operating conditions, a period which would reflect maximum fleet requirements based on both current and future ridership peaking characteristics. Consequently the results of the detailed ridership projections are particularly useful in preparing cost estimates of various staging scenarios associated with expansion of the LRT both north and south of its current operating system.

The Ridership Study has estimated that the daily ridership levels would range from 62,000 riders per day in 2021 to almost 80,000 riders per day in 2031. Sensitivity factors (e.g. rate of gasoline price increases higher than forecast) could result in even higher future ridership. For purposes of comparing the theoretical LRT and BRT system costs and operation, a **range of 60,000 to 70,000 passengers per day** was used.

These ridership figures compare very favourably with most North American LRT systems in operation today as noted in the following sample table.

SAMPLE NORTH AMERICAN LRT SYSTEM RIDERSHIP

Transit System	Length (km)	Vehicles	Riders/Day
Baltimore	40.5	40	27,400
Buffalo	11	27	23,200
Calgary	40.7	116	216,000
Cleveland	24.1	48	8,100
Dallas	70.8	95	57,000
Denver	25.4	49	35,400
Edmonton	23.8	37	42,000
OTTAWA	31.0	45-50	60 – 70,000
Pittsburgh	56.0	47	24,600
Portland(MAX)	70.6	105	98,000
St. Louis	54.7	26	41,500
Salt Lake City	30.6	42	40,000

Source: Updated from Urban Transportation Monitor Sept 3, 2004 (except for Ottawa)

5.1.2 Summary LRT, BRT and DMU Physical Characteristics

The following table provides a brief overview of LRT, BRT and DMU characteristics.

	Electric LRT	BRT	DMU
Length (metres)	28 - 30	18 - 24	48
Width (metres)	2.65	2.6	2.93
Height (metres)	3.4 – 3.9	3.4 – 3.6	3.86
Doors	Up to 4 each side	Up to 3 each side	3 each side
Typical Passenger Capacity	220 total • 70 seated • 150 standing	100 total • 40 to 60 seated • 60 to 40 standing	285 total • 135 seated • 150 standing
Propulsion	Electric, overhead catenary	Diesel, CNG, Hybrid	Diesel, Diesel-electric

5.1.3 Electric LRT versus Diesel Self Propelled Rail Cars (DMU)

The diesel self propelled Talent trains (DMUs) presently providing the existing O-Train services have proven to be excellent and attractive rail vehicles for the start up demonstration service. Many of these types of vehicles operate successfully on commuter lines in Europe where they prove to be more efficient than locomotive hauled passenger trains in lower density corridors.

The table below provides the general characteristics of electric LRT and DMUs and Appendix D provides a Transportation Research Board report on the characteristics of a number of self-propelled railcars presently in the North American market.

Rail Modes: Electric LRT and Diesel Multiple Units (DMU)

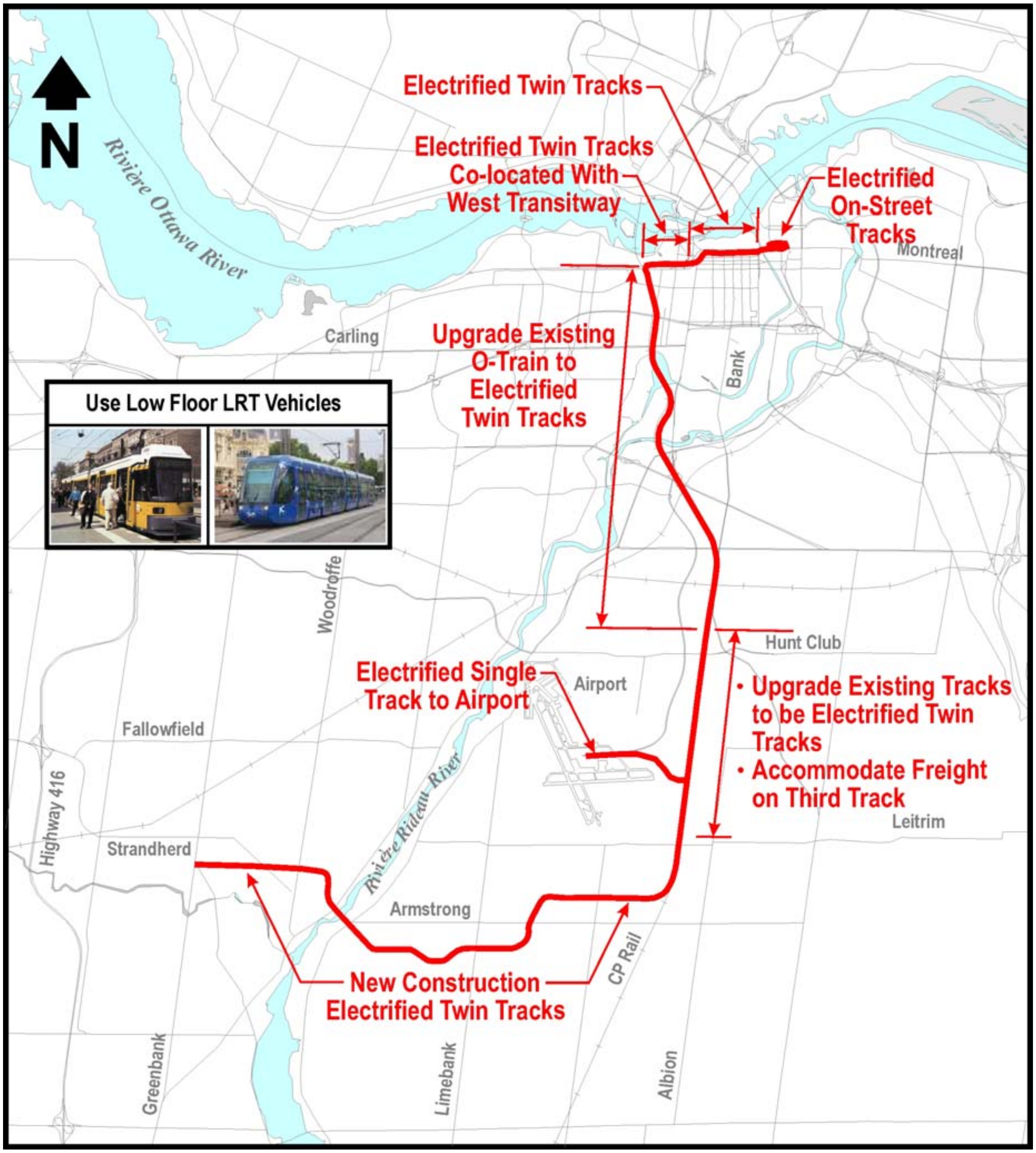
	Electric LRT	DMU
Length (metres)	28 - 30	48
Width (metres)	2.65	2.93
Height (metres)	3.4 – 3.9	3.86
Weight (kgm)	44,000	72,000
Typical Passenger Capacity	220 total • 70 seated • 150 standing	285 total • 135 seated • 150 standing
Max speed (km/h)	95-125	120
Max Practical Grade	6%	3%
Min Curve Radius (m)	25	90
Propulsion	Electricity	Diesel Fuel
Emissions	None in Corridor	Yes
Engine maintenance	Low	High

While DMU's can be excellent longer distance commuter rail vehicles, in the context of Ottawa's North-South LRT line they must be able to operate in the downtown on City streets. DMU's are generally longer, wider and heavier than a typical electric LRT vehicle and cannot negotiate tight curves making them more difficult to navigate within normal downtown traffic lanes. Because they are propelled by diesel rather than electric motors their peak power and ability to climb steeper grades is limited. The diesel engines also contribute undesirable exhaust emissions (although better than a transit bus) and require more maintenance and more frequent replacement than the typical LRT electric motor.

Because of the above factors, electric LRT is the preferred rail mode for consideration for the long term application on the North South LRT operating through the Barrhaven and Riverside South urban centres and into Ottawa's downtown.

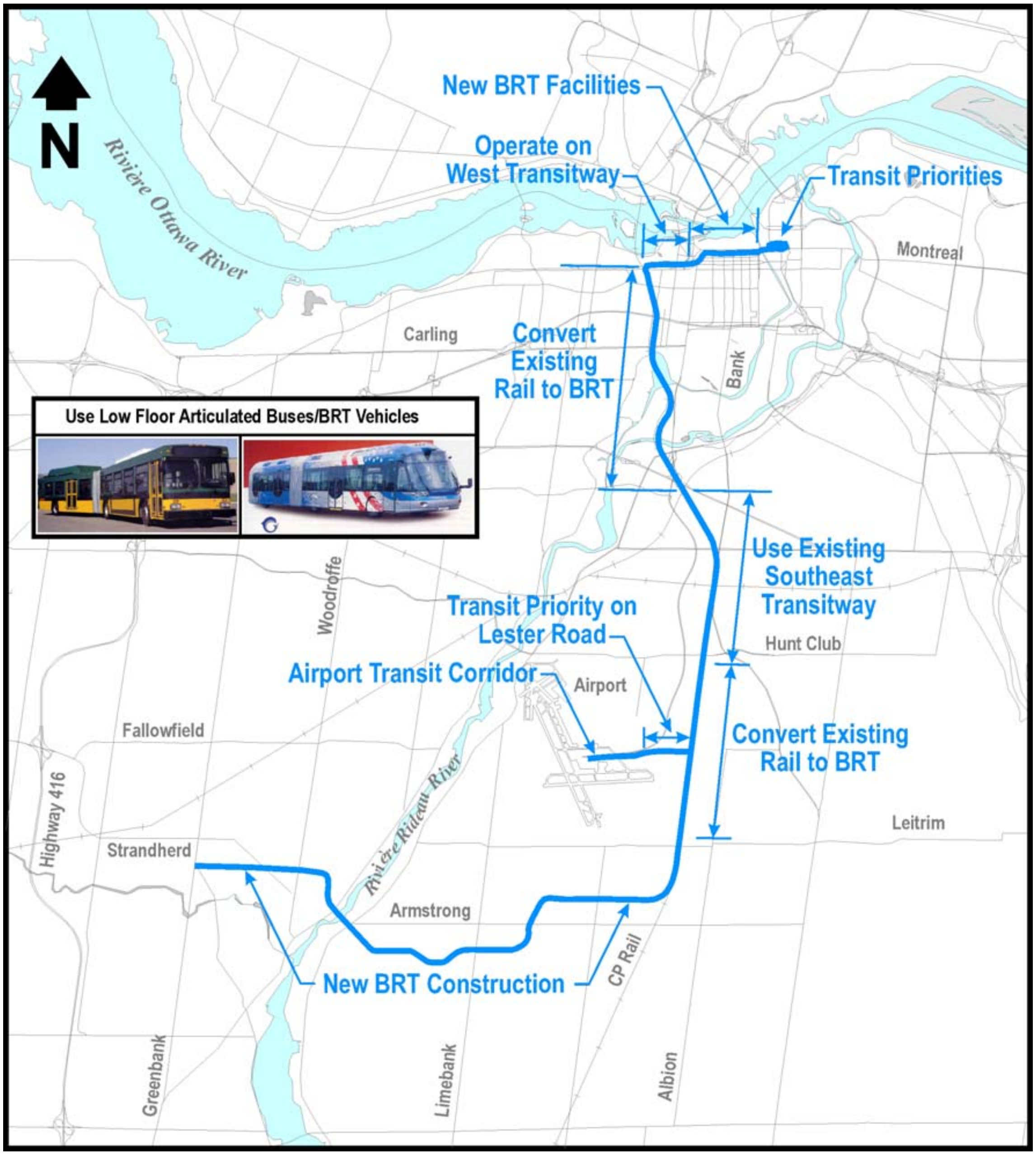
5.1.4 Assumed LRT System For Cost Comparison purposes

As shown in the figure below, the LRT system consists of approximately 29 km of twin tracks traveling from the South Nepean Town Centre, through Riverside South, past the east side of the Ottawa Macdonald-Cartier International Airport, through Carleton University, Lebreton Flats, and ending at the Rideau Centre in downtown Ottawa. There is a 2 km.single-track spur connecting the primary twin track with the Airport. For the LRT project 28 m vehicles have been considered.



5.1.5 Assumed BRT System For Cost Comparison Purposes

The figure below shows the comparative BRT system. The system consists of approximately 29 km of busway, both at-grade and grade-separated, traveling from the South Nepean Town Centre, through Riverside South, past the east side of the Ottawa Macdonald-Cartier International Airport, through Carleton University, Lebreton Flats, and into downtown Ottawa. There is busway/bus priority facility connecting the primary busway with the Airport. Where possible the buses used portions of the existing Southeast Transitway and the west transitway. Modern 23 m BRT (Civis type) vehicles have been assumed in an attempt to partially counter the image problem of the standard diesel bus.



5.1.6 LRT and BRT Headways Based on Ridership Demand

The projected future ridership, noted in Section 5.1.1, is very substantial and higher than that carried by many LRT systems in operation today. Because of the different size and passenger carrying capacity of typical LRT and BRT vehicles (a typical LRT vehicle can carry twice as many passengers as a BRT vehicle), the time between vehicles (headway) and the number of vehicles required to carry an identical number of passengers in the peak hour will be different. This has an impact on operating costs because fewer vehicles means fewer required operators.

In order to carry the projected number of peak hour riders in the study corridor the **required peak hour headways in minutes** for LRT and BRT are shown in the table below:

Vehicle Type		Headways Based on Daily Ridership	
		60,000 riders	70,000 riders
LRT (28m vehicle)	(1 car train)	2.7 minutes	2.3 minutes
	(2 car train)	5.4 minutes	4.6 minutes
BRT (articulated 23 m vehicle)		1.4 minutes	1.2 minutes

As shown, BRT vehicles can operate on shorter headways but will require more (up to approximately 4 times more) vehicles (and operators) to carry the same number of passengers as LRT.

5.2 Capital and Operating Cost

Relative planning level comparative cost of the two representative systems (discussed earlier) were developed. Cost components included capital costs for the full build-out (2021) system, annual operating costs (including operation and maintenance) and life-cycle vehicle and infrastructure replacement costs over a 50 year period. 50 years was chosen to take into account the longer life of a typical LRT vehicle which can last for up to 45 years (with refurbishment). A summary comparative table for LRT and BRT including Capital Costs (infrastructure and vehicles), Yearly Operating and Maintenance Costs, and Life Cycle Refurbish and Replacement Costs are shown in Appendix E.

5.2.1 Capital Costs

Infrastructure capital costs for LRT and BRT systems worldwide range widely depending on the location and nature of the installations. On average LRT installation costs tend to be moderately higher than BRT costs but the vehicles and systems last longer and have lower life cycle replacement costs. However, it would not be correct or appropriate to use average cost for LRT and BRT from other systems and apply them to Ottawa.

For this simplified comparative estimate certain similarities were assumed. For instance it was assumed that the stations, whether for LRT or BRT, were the same. This is a conservative assumption favouring BRT because, in reality, the typical Ottawa transitway station is larger and requires more property than that proposed for the LRT. BRT stations are quite wide and extensive because of the requirement for additional passing lanes and the need to provide structures for all passenger movements either over or under the Transitway. These BRT pedestrian structures are necessary because the buses are arriving at frequent intervals in both directions across 4 lanes of roadway.

On a comparative basis the infrastructure installation capital costs for the full build-out (2021) LRT system was estimated at approximately 18% more than an equivalent BRT system in this corridor. The LRT vehicles are also more expensive (but fewer LRT vehicles are required and they have a useful lifespan up to 3 times longer than BRT vehicles) and raised the total initial capital cost differential to approximately 28%.

As noted in “Bus or Light Rail: Making the Right Choices, Second Edition, December 2003”,

> “Cost is often quoted as the main factor for busways, but we (they) show in (their) Chapter 5 that the infrastructure costs of busways can be nearly as high as for light rail.”

5.2.2 Annual Operating Costs

In order to calculate the per hour operating costs for both LRT and BRT, it was important to develop a scenario with which one could determine the annual operating hours for either an LRT or BRT system depending on the actual forecast ridership. A simple spreadsheet model was developed and, as shown in the sample sheet in Appendix F, with an input of 70,000 (or any other number) riders per day, the annual operating hours as well as headways, number of peak and off-peak vehicles can be determined

In comparing annual operating experience for LRT and BRT, actual Ottawa operating costs were used for the BRT hourly cost assumptions. For LRT operating costs information from the USA Federal Transit administration database on the Pittsburgh and Denver systems was used. A comparative check of the Calgary LRT operating costs was also carried out.

Using these numbers, the **annual LRT operating costs are approximately 83% of the cost of operating an equivalent BRT system**, mainly because the larger LRT vehicles require fewer operators over a given time period.

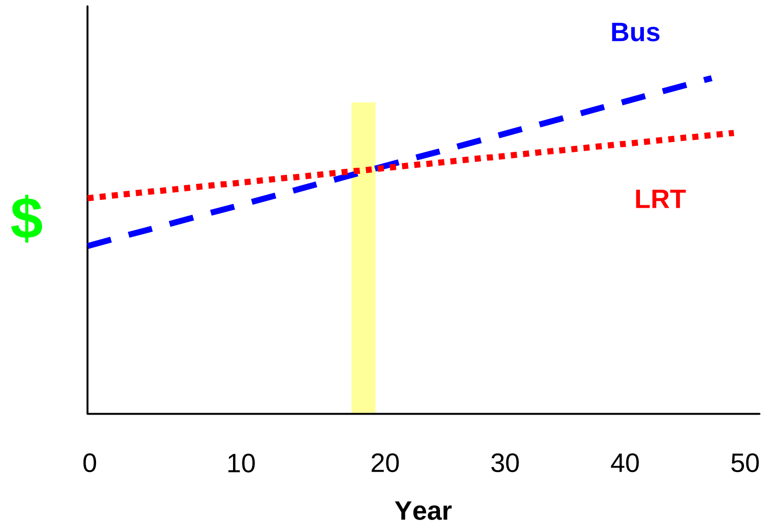
5.2.3 Life Cycle Replacement Costs

The costs of major capital vehicle and infrastructure replacement and refurbishing have been compared over a 50 year period. LRT vehicles will last 40 to 50 years assuming a major rebuild at 25 years while buses would be replaced every 15 years (on average). Based on these assumptions, the life cycle replacement costs for the LRT system are 27% of the costs for the comparable BRT system.

5.2.4 Total Long Term Costs

In terms of total costs when all three cost elements above are considered, it is clear that initial construction costs for the proposed LRT are higher than that for the assumed BRT. However, over time, the LRT savings in operating cost and life-cycle replacement costs more than compensates for the early start-up costs.

In this particular example, the break-even point (shown in the adjacent illustration) is approximately 20 years. After that, BRT is more expensive than LRT.



Cumulative Cost Comparison

5.3 Air Quality

In comparing the impact on air quality, the primary concern is in the corridor itself and more importantly in the downtown core where there is a higher concentration of vehicles. Electric LRT will not produce any atmospheric emissions in the transportation corridor - however, it may produce emissions at source of power production.

On the other hand, buses will produce atmospheric emissions, depending on the type of engine in the vehicle, as shown on the following table. For instance, the BRT vehicles carrying 60,000 riders per day will travel approximately 6,350,000 km annually. If this BRT was using a regular clean diesel engine it would produce 8,375,000 tonnes of carbon dioxide in the corridor per year. Using a diesel hybrid engine would produce 4,771,200 tonnes of carbon dioxide in the corridor per year.

The following table shows the differing levels of bus emissions allowed in 2020 based on various fuel sources and bus engines.

Bus Emission Factors (Grams per Kilometre) - Year 2020

	500 ppm S Diesel	300 ppm S Diesel Hybrid	CNG	Bio Diesel
VOC	1.03003	0.53865	2.27714	0.18473
CO	11.10083	5.77029	22.20167	3.33019
NOx	8.39762	4.36520	4.19912	10.91734
SOx	0.34770	0.28114	0.05287	0.21459
PM10	0.18971	0.09828	0.01368	0.09454
CO2	1,318.94	751.37	1,199.21	1,341.65

Source: Pg 54, Table 25, HLB Decision Economics Transportation Cost Benefit Model Manual

5.4 Ability to Attract Riders

There is a very strong perception worldwide that LRT is a more attractive transit service than buses and will attract more non-transit riders out of their cars. LRT, properly integrated with development, will also encourage more transit-related development in a given corridor. Part of this attraction is the perceived "permanence" of the corridor and part is the smoother ride quality of an LRT system. Buses also have a generally poor image because of the stereotype of diesel fumes, crowded and uncomfortable vehicles and boxlike dirty vehicles. Some of the newer more modern bus designs are attempting to overcome this image by imitating the appearance of LRT vehicles.

In spite of the improvement in BRT vehicles, the public perceives that most riders would choose an LRT vehicle if given a choice.

For those who conclude that there is a difference in attraction, reasons for the difference are given. They include the sense of permanence associated with the presence of the visible infrastructure including rails, stations, and electrification; the assurance such infrastructure gives to riders (especially those new to the city or the system) that they will reach their intended destination; the greater predictability of arrival time and overall travel times associated with transit operating in a reserved right of way; the ease of use resulting from the naming of stations; the security (in some cases) of knowing that the vehicle will stop at every station without depending on the passenger's signaling the operator; and ride comfort factors related to the quality of the alignment and the effect of guidance by means of rails.

As noted in Rail Transit In America, A Comprehensive Evaluation of Benefits, 8 November 2004 By Todd Litman Victoria Transport Policy Institute, "Rail tends to provide higher quality service than bus transit. Rail is usually more comfortable, faster (particularly if grade separated, so trains are not delayed by congestion) and better integrated into the urban landscape. As a result, rail transit usually attracts more riders within a given area, particularly discretionary riders (travelers who could drive but choose to ride transit, also called choice riders), and so is more effective than bus transit at reducing automobile trips (Pratt, 1999; FTA, 2002). One recent study found that a 10% increase in a city's rail transit service reduces 40 annual vehicle miles of travel per capita (70 VMT if New York City is included in the analysis), compared with just a one mile reduction from a 10% increase in bus service (Bento, et al, 2004)."

The American Public Transportation Association reports that, for 2004, US transit ridership increased 2.1% over 2003 – to 9.6 billion rider-trips – with light rail transit (LRT) gaining 8.2%, rapid rail 3.0%, motor bus 2.4%, and regional "commuter" rail 0.3%. Thus LRT led all other major transit modes in its growth rate. [Mass Transit, 2005/03/29]

5.5 Ability to Attract Development

Similar to its attractiveness to riders, rail transit has permanence and "look" that also attracts higher levels of land development. One of the main purposes of the North South LRT project is in fact to lead development in the proposed 52,000 Riverside South Community and encourage the "transit habit" from the outset.

As noted in Rail Transit In America, A Comprehensive Evaluation of Benefits, "Transit oriented land use patterns can increase property values and economic productivity by improving accessibility, reducing costs, improving livability and providing economies of agglomeration. In some cases, increased property values offset most or all transit subsidy costs. This does not generally occur with bus service".

5.6 Noise and Vibration

5.6.1 Noise

As noted in the table below, the pass-by noise levels for rail and bus transit technologies considered are very similar, with electric LRT being slightly quieter. With respect to acceleration/deceleration there is a noticeable difference between BRT and LRT vehicles. For diesel engines, this increase in ambient noise is quite intrusive whereas electric LRT vehicles have no noticeable start-up sound increase.

Representative Sound Levels For Bus and LRT

Method of Transportation	Pass-by Lmax (dBA)	Acceleration/ Deceleration (dB)
Diesel Bus	74[1]	70-75[4]
LRT – Electric	72[2]	60-65[4]
LRT – Diesel	74[3]	NA

Notes: 1. Sound levels were obtained by measurement in a controlled passby study conducted by RWDI for the Region of Waterloo on September 13, 2004
2. Sound levels were obtained using MOE Stamson / STEAM prediction software for the Scarborough Rapid Transit using the train speed and a triangular passby time history to determine the Lmax sound level.
3. Sound levels were obtained from a previous RWDI report on the Ottawa LRT Pilot Project submitted to the City of Ottawa on April 29, 2002. RWDI Ref.# 01-613.
4. November 2003, Proceedings of the Institute of Civil Engineers. "Which Technology for Urban Public Transport?". Pg. 207

In each of the above pass-by cases, a source/receiver distance of 15 m was used and a receiver height of 1.5 m above the source were used in determining the Lmax sound level. Sound levels for each source was calculated or measured at a vehicle operating speed of 65 kph.

It should be noted that pass-by levels are related to a single vehicle movement. Noise impacts can also have a cumulative or exposure impact, which depends on the total number of vehicle movements over time (typically one hour). Thus the impacts are related to the number of passenger movements and the vehicle capacity of the transportation mode. For example, if the LRT mode handles the passenger load with 12 trains per hour it might be substantially better than buses, which may require 46 movements to carry the same passenger demand.

5.6.2 Vibration

As noted in the table below, vibration levels for the lighter BRT vehicles will be less than those of the heavier LRT vehicles. While vibration from LRT vehicles is higher than that of buses (except where buses cross a structural expansion joint and create a fairly large vibration from the impact) the typical LRT vibration is not intrusive and can be mitigated where sensitive receptors are an issue.

Representative Vibration Levels for Bus and LRT

Method of Transportation	Vibration Level (VdB)	
Bus[1]	55'	58'
LRT – Electric [2]	63	
LRT – Diesel [3]	63	

Notes:

1. Vibration levels were obtained from the FTA Handbook and adjusted for speed. The 55 VdB value corresponds to a speed of about 50 kph, which is typical city bus speed. The 58 VdB value corresponds to a speed of 65 kph after adjustments have been made to compare with the LRT levels.
2. Vibration levels were obtained from the FTA handbook and adjusted for speed.
3. Vibration levels were obtained from previous report submitted to the Regional Municipality of Ottawa and Dillon Consulting Ltd. on May 7, 1999. RWDI Ref. #99-171-9.

5.7 Capability of Accommodating More Buses in the Downtown

Because of the success of the bus systems in Ottawa and Gatineau, the ability of downtown Ottawa to accept more buses, both physically and environmentally, has reached a saturation point.

There are currently two primary east-west transit corridors in central Ottawa:

1. The Albert/Slater pair of one-way streets joined to the Mackenzie King Bridge across the Rideau Canal. This is the connection to the West Transitway starting in LeBreton Flats and to the Southeast Transitway starting at Laurier Avenue. The corridor currently is served by approximately 170 buses per peak hour per direction and is generally considered to be at capacity, with existing operational problems during the peak period. All of the core Transitway services (routes 95, 96 and

97) use the corridor along with all of the downtown peak period only routes serving residential areas throughout the urban area.

2. The Rideau Street (east of the Rideau Canal) and Wellington Street (west of the Canal) corridor accommodates transit service from two transit agencies. OC Transpo's downtown service that doesn't use the Transitway uses the corridor east of Bank Street. These routes serve many of the older urban areas that have been served by similar routes for at least the past 35 years. All of STO's routes that enter downtown Ottawa use the corridor between the Portage Bridge and King Edward Avenue. Bus volumes on the corridor during the peak periods range from 70 to 140 buses, depending on the direction and the time period.

As the City population and employment increases, ridership and the number of buses required for service on the **existing transitways** will continue to grow. This growth in buses can be accommodated on outlying portions of each transitway but **not where they converge in the downtown**. As the city grows, bus-based transit demand in will increase, even with the implementation of LRT in Ottawa. Special operating plans (hub and spoke) are presently being developed to address this issue and to minimize the number of buses in the downtown.

In addition to the physical and operational capacity issues related to the present bus service in the downtown, it has also been made clear through the public consultation process that there is a desire for fewer buses in the downtown because of environmental and social issues - including exhaust fumes, diesel noise and image of the Nation's capital.

Additional bus service from a new north-south transit corridor into the downtown is not an acceptable option and would only exacerbate an existing problem.

5.8 Service Flexibility

Because LRT vehicles can only operate where there are tracks, they are not as flexible as a BRT vehicle. BRT vehicles can start on any city street and enter the Transitway at any connection point on the route. They can also leave the Transitway and use other routes in the event of an emergency closure. LRT vehicles are restricted in that regard but are better able to deal with adverse weather conditions by maintaining close to normal speed.

6.0 Summary Evaluation

6.1 Evaluation Summary

The following table highlights the various key factors discussed earlier in comparing rail and bus in Ottawa's North-South Rapid Transit Corridor.

LRT/BRT Comparative Summary Table

		LRT	BRT	Additional Notes
2021 passenger demand	60,000 - 70,000 daily			
Vehicle/train design capacity	1car/bus (passengers) 2 car LRT train	145 290	75 N/A	28m LRT
Peak hour headways (min)	60,000 daily riders 70,000 daily riders	2.7 2.3 - 4.6	1.4 1.2	 1-2 car train
Operators required/peak hr	60,000 daily riders 70,000 daily riders	38 23 - 45	70 83	 2-1 car train
Ability to attract new riders		Better	Good	
Passenger comfort		Best	Fair	
Air pollution in corridor		None	Higher	
Noise		Same	Same	Acceptable
Vibration		Slightly Higher	Low	Acceptable
Bus saturation in the downtown		Will reduce existing bus level	Unacceptable Would add 70-80 more buses/hr	
Service flexibility		Less flexible	More flexible	
<u>Comparative costs</u>				
Capital cost		1.28	1	
Annual operating cost		0.83	1	
Life Cycle Replacement Cost		0.27	1	
Total Long Term Cost		Base	Higher	

6.2 Conclusions

When considering all of the factors related to rapid transit service in the North South transportation corridor, Rail (LRT) is preferred because:

1. The LRT service could be operated with approximately 1/3 the number of drivers, (for the example comparative system discussed previously: 23 LRT drivers versus 83 BRT drivers), with the consequent saving in operating costs.
2. The existing Transitway through the downtown is at capacity and cannot accommodate any additional buses. A new BRT rather than LRT service would contribute up to 80 additional buses per hour.
3. LRT will not add to the atmospheric emissions in the corridor whereas, even "cleaner" diesel or hybrid buses will add significant contaminants, especially in the already congested downtown area.
4. The projected ridership level is similar to or higher than most other North American LRT systems.
5. The large central portion of the north-south corridor is already an existing rail corridor.
6. The LRT will attract more riders and more significant development adjacent to the corridor especially in the Bayview, LeBreton Flats and Riverside South areas.
7. While the LRT is more expensive to implement, the savings in operating and life cycle replacement costs more than compensate over time.

6.3 Suggested LRV Design Criteria for Ottawa

This survey of Light Rail Vehicles provides information on several models that would be suitable for use on Ottawa's North-South Corridor. Based on the typical physical and performance characteristics of vehicles manufactured for the North American market, some general design parameters can be derived. The suggested design parameters are listed below, and apply only to electric Light Rail Vehicles.

The following design parameters are suggested:

- Power Supply — 600 Vdc to 750 Vdc
- Maximum Speed — 85 km/h or higher
- Service Acceleration — 1.25 m/s^2 or higher
- Maximum Grade — 5% or higher
- Minimum Turning Radius — 25 m
- Floor Height at Entrance — 0.4 m or lower
- Maximum Length — 28 m to 40 m

- Maximum Height 3.89 m
- Maximum Width 2.74 m
- Passenger Capacity 150 total or higher
- Visibility Good

These design parameters have been chosen to allow for a variety of vehicle choices.

APPENDIX A
SAMPLE LRT/DMU VEHICLES

BOMBARDIER FLEXITY SWIFT – Minneapolis, MN

Performance and Technical Data

• Catenary Supply Voltage	750 Vdc
• Maximum Operational Speed	88.5 km/h
• Maximum Operational Grade	5%
• Minimum Turning Radius	25 m
• Minimum Vertical Radius	250 m crest, 350 m sag
• Service Acceleration	1.34 m/s^2
• Service Deceleration	1.34 m/s^2
• Emergency Deceleration	3.4 m/s^2
• Visibility	Good

Physical Data

• Possible Unit Configurations	Up to 3 vehicles
• Passenger Capacity	66 seated, 180 standing, 4 wheelchair
• Length Over Coupler Faces	28.65 m
• Width	2.65 m
• Height	3.78 m
• Floor Height Above Top of Rail	0.355 m (low floor), 0.695 (high floor)
• Doors on Each Side	4 bi-parting sliding plug
• Track Gauge	1.435 m
• Empty Weight	48.5 t

SKODA-INEKON 10T – Tacoma, WA & Portland, OR

Performance and Technical Data

• Catenary Supply Voltage	600 Vdc / 750 Vdc
• Maximum Operational Speed	70 km/h
• Maximum Operational Grade	8%
• Minimum Turning Radius	18 m
• Minimum Vertical Radius	250 m
• Service Acceleration	1.40 m/s^2
• Service Deceleration	1.30 m/s^2
• Emergency Deceleration	2.90 m/s^2
• Visibility	Good

Physical Data

• Possible Unit Configurations	Single vehicle
• Passenger Capacity	30 seated, 127 standing, 2 wheelchair
• Length Over Coupler Faces	20.09 m
• Width	2.46 m
• Height	3.89 m
• Floor Height Above Top of Rail	0.350 m (low floor), 0.780 (high floor)
• Doors on Each Side	2 double-wing, 1 single-wing
• Track Gauge	1.435 m
• Empty Weight	28 t

SIEMENS S70 – Charlotte, NC

Performance and Technical Data

• Catenary Supply Voltage	750 Vdc
• Maximum Operational Speed	106 km/h
• Maximum Operational Grade	7%
• Minimum Turning Radius	25 m
• Minimum Vertical Radius	250 m crest, 350 m sag
• Service Acceleration	1.34 m/s^2
• Service Deceleration	1.34 m/s^2
• Emergency Deceleration	2.20 m/s^2
• Visibility	Good

Physical Data

• Possible Unit Configurations	1, 2, or 3 cars
• Passenger Capacity	68 seated, 168 standing, 4 wheelchair
• Length Over Coupler Faces	28.53 m
• Width	2.65 m
• Height	3.68 m
• Floor Height Above Top of Rail	0.356 m (low floor), 0.856 m (high floor)
• Doors on Each Side	4 sliding plug
• Track Gauge	1.435 m
• Empty Weight	44 t

SIEMENS S70 – Houston, TX

Performance and Technical Data

• Catenary Supply Voltage	750 Vdc (1500 Vdc optional)
• Maximum Operational Speed	106 km/h
• Maximum Operational Grade	7%
• Minimum Turning Radius	25 m
• Minimum Vertical Radius	250 m crest, 350 m sag
• Service Acceleration	1.34 m/s^2
• Service Deceleration	1.34 m/s^2
• Emergency Deceleration	2.20 m/s^2
• Visibility	Good

Physical Data

• Possible Unit Configurations	Up to 4 vehicles
• Passenger Capacity	64 seated, 148 standing, 4 wheelchair
• Length Over Coupler Faces	29.37 m
• Width	2.65 m
• Height	3.68 m
• Floor Height Above Top of Rail	0.356 m (low floor), 0.669 m (high floor)
• Doors on Each Side	4 sliding plug
• Track Gauge	1.435 m
• Empty Weight	44 t

KINKI SHARYO LOW FLOOR VEHICLE – San Jose, CA

Performance and Technical Data

• Catenary Supply Voltage	750 Vdc
• Maximum Operational Speed	90 km/h
• Maximum Operational Grade	6.5%
• Minimum Turning Radius	25 m
• Minimum Vertical Radius	506 m
• Service Acceleration	1.34 m/s^2
• Service Deceleration	1.56 m/s^2
• Emergency Deceleration	2.35 m/s^2
• Visibility	Good

Physical Data

• Possible Unit Configurations	Up to 3 cars
• Passenger Capacity	65 seated, 105 standing
• Length Over Coupler Faces	27.11 m
• Width	2.65 m
• Height	3.38 m
• Floor Height Above Top of Rail	0.350 m (low floor), 0.900 m (high floor)
• Doors on Each Side	4 sliding plug
• Track Gauge	1.435 m
• Empty Weight	44.2 t

BOMBARDIER GTW 2/6 DMU – River Line, NJ

Performance and Technical Data

• Power Supply	Diesel-Electric
• Maximum Operational Speed	96 km/h
• Maximum Operational Grade	6%
• Minimum Turning Radius	40 m
• Minimum Vertical Radius	N/A
• Service Acceleration	0.90 m/s^2
• Service Deceleration	1.00 m/s^2
• Emergency Deceleration	2.00 m/s^2
• Visibility	Good

Physical Data

• Possible Unit Configurations	1 or 2 cars
• Passenger Capacity	90 seated, 94 standing, 2 wheelchair
• Length Over Coupler Faces	31.24 m
• Width	3.00 m
• Height	3.91 m
• Floor Height Above Top of Rail	0.584 m (low floor), 0.999 (high floor)
• Doors on Each Side	2 bi-parting sliding plug
• Track Gauge	1.435 m
• Empty Weight	55 t

BOMBARDIER Talent DMU – Ottawa, ON

Performance and Technical Data

• Power Supply	Diesel-Mechanical
• Maximum Operational Speed	120 km/h
• Maximum Operational Grade	3.5%
• Minimum Turning Radius	90 m
• Minimum Vertical Radius	500 m
• Service Acceleration	0.83 m/s^2
• Service Deceleration	0.95 m/s^2
• Emergency Deceleration	1.10 m/s^2
• Visibility	Fair

Physical Data

• Possible Unit Configurations	Up to 3 cars
• Passenger Capacity	135 seated, 150 standing
• Length Over Coupler Faces	48.36 m
• Width	2.93 m
• Height	3.86 m
• Floor Height Above Top of Rail	0.590 m (low floor)
• Doors on Each Side	1 twin-flap
• Track Gauge	1.435 m
• Empty Weight	72 t

APPENDIX B
DETAILED SPECIFICATION CHART
SAMPLE RAIL VEHICLES

Electric Light Rail Vehicles

	Manufacturer and Vechicle Name	Description	Location Example & Delivery Year	Power Supply	Possible Unit Configurations	Passenger Capacity	Max Speed (Operational)	Maximum Grade	Minimum Turning Radius	Minimum Vertical Radius	Length	Width	Vehicle Height	Floor Height From Top of Rail	Doors on Each Side	Track Gauge	Empty Weight	Service Acceleration	Service Deceleration	Emergency Deceleration	Visibility	Comments
1	Ansaldo Breda San Francisco LRT	Articulated, bi-direc, 2 motor trucks, 1 trailer truck	San Francisco, 1996	600 Vdc Pantograph	3 cars	60 seated 70 standing	80 km/h	9%	14 m	N/A	22.86 m	2.74 m	3.51 m	0.864 m	N/A	1.435 m	36 t	1.41 m/s^2	1.79 m/s^2	2.68 m/s^2	Good	
2	Ansaldo Breda Type 8 Low Floor	Double articulated LRV, 2 motor trucks, 1 trailer truck	Boston, 1998	650 Vdc Pantograph	N/A	46 seated 120 standing 2 wheelchair	88.5 km/h	9%	13 m	N/A	22.56 m	2.64 m	3.60 m	0.356 m (low floor) 0.889 m (high floor)	3 double width	1.435 m	39 t	1.25 m/s^2	1.56 m/s^2	2.68 m/s^2	Fair	
3	Ansaldo Breda Sirio LRV Base	Continuous low floor	Many cities throughout Europe	overhead electrical or embedded power rail	N/A	flexible	N/A	N/A	15 m	N/A	20 m to 42 m	2.30 m to 2.65 m	flexible	0.350 m	N/A	N/A	N/A	N/A	N/A	N/A	Good	
4	Ansaldo Breda Sirio LRV Florence	Continuous low floor	Florence	750 Vdc	N/A	42 seated 2 wheelchair 160 standing	70 km/h	N/A	N/A	N/A	31.90 m	2.40 m	3.30 m	0.350 m	N/A	1.445 m	N/A	N/A	N/A	N/A	Good	
5	Ansaldo Breda Sirio LRV Sassari	Continuous low floor Bi-directional	Sassari	750 Vdc Pantograph	N/A	38 seated 151 standing	N/A	N/A	N/A	N/A	27.47 m	2.40 m	3.30 m	N/A	4	0.950 m	N/A	N/A	N/A	N/A	Good	
6	Bombardier Flexity Swift BOC-LF-70	70% Low floor, 3-car, Bi-directional	Minneapolis, 2004	Electrical pantograph, IGBT 750Vdc catenary	Up to 3 vehicles	66 seated 180 standing 4 wheelchair	88.5 km/h	5%	25 m	250 m crest 350 m sag	28.65 m	2.65 m	3.78 m	0.355 m (low floor) 0.695 m (high floor)	4 bi-parting sliding plug	1.435 m	48.5 t	1.34 m/s^2	1.34 m/s^2	3.4 m/s^2	Good	Bombardier's first N. American low-floor LRV
7	Bombardier Flexity Link Bi-directional	50% Low floor, adaptable, Runs on heavy and light rail networks	Saarbrucken, 1997	Electrical dual voltage 750Vdc and 15kV 16 2/3 Hz, IGBT	1 vehicle	96 seated 147 standing 2 wheelchair	100 km/h	8%	25 m	500 m	37.90 m	2.65 m	3.80 m	0.400 m (low floor) 0.600 m (high floor) 0.805 m (high floor)	4 bi-parting sliding plug	1.435 m	55.4 t	1.1 m/s^2	1.6 m/s^2	2.8 m/s^2	Good	
8	Bombardier Flexity Classic	70% Low-floor, uni-directional	Dessau, Germany (example of modification)	Electrical pantograph, IGBT	1 vehicle	52 seated 67 standing	70 km/h	4%	30 m	500 m	21.07 m	2.30 m	3.49 m	0.290 m (entrance) 0.360 m (low floor) 0.580 m (at bogie)	2 bi-parting 1 single sliding plug	1.435 m	27.1 t	1.04 m/s^2	1.33 m/s^2	2.73 m/s^2	Good	
9	Bombardier Flexity Classic	70% Low-floor, bi-directional, adaptable	Essen, Germany (all over Germany)	Electrical pantograph, IGBT	1 vehicle	70 seated 91 standing	70 km/h	7%	18 m	500 m	28.00 m	2.30 m	3.50 m	0.300 m (entrance) 0.360 m (low floor) 0.560 m (at bogie)	3 bi-parting sliding plug	1.000 m	36.5 t	1.3 m/s^2	1.4 m/s^2	2.73 m/s^2	Good	
10	Bombardier Flexity Outlook	100% Low-floor	Linz, Austria (pilot)	Electrical pantograph, IGBT	1 vehicle	71 seated 156 standing	70 km/h	6%	17 m	500 m	40.00 m	2.30 m	3.50 m	0.300 m (entrance) 0.360 m (low floor) 0.560 m (at bogie)	3 bi-parting sliding plug	0.900 m	36.5 t	1.3 m/s^2	1.4 m/s^2	2.73 m/s^2	Good	
11	Bombardier Flexity Outlook Tram	100% Low-floor	Lodz, Poland, 2002 (example of modification)	Electrical pantograph, IGBT	1 vehicle	59 seated 99 standing	70 km/h	5%	17 m	500 m	29.50 m	2.30 m	3.50 m	0.320 m (entrance)	4 bi-parting 2 single sliding plug	1.000 m	34.2 t	1.4 m/s^2	1.4 m/s^2	2.8 m/s^2	Good	
12	Bombardier Flexity Outlook Tram	100% Low-floor Regenerative brakes	Milan, Italy, 2000 (example of modification)	Electrical pantograph, IGBT	1 vehicle	68 seated 124 standing	70 km/h	6%	18 m	250 m	34.10 m	2.47 m	3.19 m	0.350 m	6 bi-parting sliding plug one side only	1.445 m	41.5 t	1.0 m/s^2	1.2 m/s^2	2.2 m/s^2	Good	
13	CAF Sacramento LRV 200 Series	Single-articulated, Bi-directional, high floor	Sacramento, 2002-03	750 Vdc. Catenary overhead electrical	N/A	88 seated 152 standing 4 wheelchair	88.5 km/h	N/A	N/A	N/A	24.71 m	2.67 m	3.79 m	0.985 m	4 sliding plug	1.435 m	48 t	1.34 m/s^2	1.34 m/s^2	2.0 m/s^2	Good	
14	CAF Pittsburgh LRV	Two-way articulated, 2 motor bogies, 1 trailer bogie	Pittsburgh, 2003	650 Vdc. Catenary overhead electrical	N/A	62 seated 150 standing	96 km/h	N/A	N/A	N/A	24.90 m	2.68 m	3.66 m	0.990 m	3	1.588 m	N/A	1.1 m/s^2	1.3 m/s^2	1.3 m/s^2	Fair	
15	CAF Articulated Train Unit	2 articulated coaches rest on 3 bogies	Monterrey, Mexico	1500 Vdc. Catenary overhead electrical	N/A	58 seated 222 standing	80 km/h	N/A	N/A	N/A	29.56 m	2.65 m	3.75 m	1.020 m	6	1.500 m	N/A	1.0 m/s^2	1.0 m/s^2	1.3 m/s^2	Fair	
16	CAF Articulated Train Unit	2 articulated coaches rest on 3 bogies	Valencia, 1994	1500 Vdc. Catenary overhead electrical	N/A	80 seated 160 standing	80 km/h	N/A	N/A	N/A	29.80 m	2.55 m	3.37 m	1.150 m	2	1.000 m	N/A	0.86 m/s^2	1.0 m/s^2	1.2 m/s^2	Good	
17	CAF Articulated Train Unit	2 articulated coaches rest on 3 bogies	Tren de la Costa - Argentina, 1995	1500 Vdc. Catenary overhead electrical	N/A	80 seated 160 standing	80 km/h	N/A	N/A	N/A	29.80 m	2.55 m	3.75 m	1.050 m	4	1.435 m	N/A	1.0 m/s^2	1.0 m/s^2	1.2 m/s^2	Good	
18	CAF 70% Low floor Tram	3 articulated units rest on 3 bogies, one-way vehicle, low floor	Lisbon, 1995 Valencia, 1994, 1999	750 Vdc. Catenary overhead electrical	N/A	65 seated 181 standing	65 km/h	N/A	N/A	N/A	23.78 m	2.40 m	3.22 m	0.350 m	4 on right side only	1.000 m	N/A	0.8 m/s^2	1.2 m/s^2	1.6 m/s^2	Good	
19	CAF 70% Low floor Tram	3 articulated units rest on 3 bogies, two-way vehicle, low floor access	Bilbao	750 Vdc. Catenary overhead electrical	N/A	48 seated 148 standing	70 km/h	N/A	N/A	N/A	24.41 m	2.40 m	3.30 m	0.350 m	4	1.000 m	N/A	1.08 m/s^2	1.20 m/s^2	2.35 m/s^2	Good	
20	CAF 100% Low floor Tram	5 articulated bogies	Bilbao, 2002	750 Vdc. Catenary overhead electrical	N/A	48 seated 148 standing	70 km/h	N/A	N/A	N/A	24.41 m	2.40 m	3.30 m	0.350 m	4	1.000 m	N/A	1.18 m/s^2	1.25 m/s^2	2.35 m/s^2	Good	
21	Kawasaki Series 100	One-directional, 4-axle	Philadelphia, 1982	N/A	Single vehicle	51 seated 39 standing	80 km/h	5%	22 m	N/A	15.2 m	2.6 m	3.4 m	0.914 m	N/A	1.581 m	26.3 t	1.30 m/s^2	N/A	N/A	Fair	
22	Kawasaki LRV	Motor car with driver cab or motored trailer car	Hong Kong	750 Vdc Catenary	Up to 3 cars	N/A	80 km/h	N/A	N/A	N/A	20.20 m	2.65 m	3.87 m	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Fair	
23	Kinki Sharyo Super Light Rail Vehicle	Single-articulated, High floor	Dallas, 1996, 1999, 2000	750 Vdc Overhead trolley	Up to 4 cars	76 seated 84 standing 4 wheelchair	105 km/h	7%	25 m	500 m	27.74 m	2.69 m	3.53 m	1.003 m	4 sliding	1.435 m	49.9 t	1.34 m/s^2	1.34 m/s^2	2.68 m/s^2 (for speeds below 48 km/h)	Good	
24	Kinki Sharyo Low Floor Vehicle	70% Low floor Double-articulated	San Jose, 2001, 2004	750 Vdc Overhead trolley	Up to 3 cars	65 seated 105 standing	90 km/h	6.5%	25 m	506 m	27.11 m	2.65 m	3.38 m	0.350 m (low floor) 0.900 m (high floor)	4 sliding plug	1.435 m	44.2 t	1.34 m/s^2	1.56 m/s^2	2.35 m/s^2	Good	
25	Kinki Sharyo Low Floor Vehicle	70% Low Floor, 2 way, Double-articulated	Hudson-Bergen, NJ, 2000 Newark, 1999	750 Vdc Overhead trolley	3 cars (normal) 6 (emergency)	72 seated 122 standing	88.5 km/h	7%	18 m	250 m crest 350 m sag	26.74 m	2.68 m	3.63 m	0.350 m (low floor) 0.890 m (high floor)	4 sliding plug	1.435 m	45 t	1.34 m/s^2	1.34 m/s^2	2.01 m/s^2	Good	
26	Nippon Sharyo LAHT LRV	2-Section articulated High platform	Los Angeles, 1990, 1994	750 Vdc	4 units	76 seated 161 standing	88.5 km/h	6%	25 m	500 m	27.13 m	2.66 m	3.78 m	0.991 m	4	1.435 m	44.5 t	1.34 m/s^2	1.56 m/s^2	1.79 m/s^2	Good	

	Manufacturer and Vechicle Name	Description	Location Example & Delivery Year	Power Supply	Possible Unit Configurations	Passenger Capacity	Max Speed (Operational)	Maximum Grade	Minimum Turning Radius	Minimum Vertical Radius	Length	Width	Vehicle Height	Floor Height From Top of Rail	Doors on Each Side	Track Gauge	Empty Weight	Service Acceleration	Service Deceleration	Emergency Deceleration	Visibility	Comments
27	Siemens Type S70	3-section articulated, 70 % low floor, uni- or bi-directional	Base model	DC 600V / 750V	Up to 4 vehicles	83 uni-direc 64 bi-direc	105 km/h	7%	20 m	250 m	26.5 m	2.40 m or 2.65 m	3.52 m	0.356 / 0.381 m (low floor area) 0.655 m (high floor)	4 sliding plug	1.435 m	44 t	1.34 m/s^2	1.34 m/s^2	2.20 m/s^2	Good	Never been offered in this version
28	Siemens Type S70	5-section articulated, 80 % low floor, uni- or bi-directional	Base model	DC 600V / 750V or DC 1500V / 3000V (mainline tracks) or AC 15kV / 25kV (Diesel-hybrid)	Up to 4 vehicles	119 uni-direc 96 bi-direc	105 km/h	7%	20 m	250 m	36.5 m	2.40 m or 2.65 m	3.52 m	0.356 / 0.381 m (low floor area) 0.655 m (high floor)	4 sliding plug	1.435 m	44 t	1.34 m/s^2	1.34 m/s^2	2.20 m/s^2	Good	Never been offered in this version
29	Siemens S70 - Houston	70% low floor, articulated, bi-directional	Houston, 2003	750Vdc catenary (1500Vdc optional) rooftop IGBT inverter	Up to 4 vehicles	64 seated 4 wheelchair 148 standing	106 km/h	7%	25 m	250 m crest 350 m sag	29.37 m	2.65 m	3.68 m without pantograph	0.356 m (low floor) 0.669 m (high floor)	4 sliding plug	1.435 m	44 t	1.34 m/s^2	1.34 m/s^2	2.20 m/s^2	Good	Recommended by Siemens
30	Siemens S70 - San Diego	3-section, 70% Low floor, articulated, bi-directional	San Diego, 2004	600 Vdc rooftop IGBT inverter	Dependent on stations	56 seated 94 standing 4 wheelchair	88.5 km/h	6%	25 m	250 m crest 350 m sag	27.67 m	2.65 m	3.61 m without pantograph	0.356 m (low floor) 0.381 m (low floor) 0.855 m (high floor)	4 sliding plug	1.435 m	43 t	1.34 m/s^2	1.34 m/s^2	2.33 m/s^2	Good	Recommended by Siemens
31	Siemens S70 CATS LRV	70% low floor, articulated, bi-directional	Charlotte, NC, 2005 in progress	750 Vdc Catenary IGBT	1, 2, or 3 cars	68 seated 168 standing 4 wheelchair	106 km/h	7%	25 m	250 m crest 350 m sag	28.53 m	2.65 m	3.68 m without pantogrpah	0.356 m (low floor) 0.856 m (high floor)	4 sliding plug	1.435 m	44 t	1.34 m/s^2	1.34 m/s^2	2.2 m/s^2	Good	Recommended by Siemens
32	Siemens SD-100	2-section, bi-directional, Single-articulated	Salt Lake City, 1999, Denver, 1995, 99, San Diego, 1993-95	750 Vdc catenary 600 Vdc (San Diego)	Up to 4 vehicles	64 seated 120 standing	88.5 km/h	4%, 7% (Salt Lake)	25 m	250 m - 350 m crest and sag	24.5 m	2.70 m	3.78 m	0.914 m (Salt Lake) 0.991 m (Denver)	4	1.435 m	40 t	1.35 m/s^2	1.35 m/s^2	2.3 m/s^2 2.01 (Salt Lake)	Good	
33	Siemens SD-160	bi-directional, high floor, single-articulated	Calgary, 2001, 2002	600-750 Vdc catenary IGBT	Dependent on stations	60 seated 240 standing	80 km/h	6%	25 m	460 m	24.6 m	2.65 m	3.84 m	0.985 m	4	1.435 m	40 t	1.34 m/s^2	1.25 m/s^2	1.56 m/s^2	Good	
34	Siemens SD-160	bi-directional, high floor, single-articulated	Salt Lake City, 2002	750 Vdc catenary IGBT	Dependent on stations	56 seated 4 wheelchair 184 standing	105 km/h	7%	25 m	350 m crest 250 m sag	24.82 m	2.65 m	3.84 m	0.985 m	4	1.435 m	40 t	1.25 m/s^2	1.34 m/s^2	2.2 m/s^2	Good	
35	Siemens SD 460	Single-articulated, bi-directional, high floor	St. Louis, 1998-99	750 Vdc catenary	Dependent on stations	72 seated 106 standing	105 km/h	7%	25 m	228.6 m	27.264 m	2.65 m	3.80 m	1.006 m	4 bi-folding platform level	1.435 m	42 t	1.34 m/s^2	1.34 m/s^2	2.55 m/s^2	Fair	
36	Skoda-Inekon 10 T Two-way, Low-floor streetcar	3-section, bi-directional, articulated, 50% low floor, 2 non-rotating bogies	Portland, 2001-02 Tacoma, 2002	DC 600V / 750V IGBT inverter roof mounted	Single vehicle	30 seated 141 standing 2 wheelchair	70 km/h	6%	18.2 m	N/A	20.13 m	2.46 m	3.44 m	0.350 m (low floor) 0.780 m (high floor)	2 double-wing 1 single-wing	1.435 m	28.8 t	N/A	N/A	N/A	Good	
37	Skoda Modernized Tramcar T3	N/A	N/A	600 V IGBT transistors	N/A	54 seated 139 standing (crush)	60 km/h	N/A	N/A	N/A	15.10 m	2.50 m	3.06 m	N/A	N/A	N/A	16.5 t to 18.5 t	1.65 m/s^2	N/A	N/A	Good	

Diesel Multiple Units

	Manufacturer and Vechicle Name	Description	Location Example & Delivery Year	Power Supply	Possible Unit Configurations	Passenger Capacity	Max Speed (Operational)	Maximum Grade	Minimum Turning Radius	Minimum Vertical Radius	Length	Width	Vehicle Height	Floor Height From Top of Rail	Doors on Each Side	Track Gauge	Empty Weight	Service Acceleration	Service Deceleration	Emergency Deceleration	Visibility	Comments
38	Bombardier Talent BR643 DMU	72% Low-floor, 3-car articulated	Ottawa, 2001	Diesel-mechanical	3 cars	135 seated 150 standing	120 km/h	3.5%	90 m	500 m	48.36 m	2.93 m	3.86 m	0.590 m (low floor)	1 twin-flap	1.435 m	72 t	0.83 m/s^2	0.95 m/s^2	1.1 m/s^2	Fair	
39	Statler/Bombardier River Line DMU GTW 2/6	2 trailers, 1 power unit each, articulated	River Line - Trenton and Camden, NJ, 2000-01	Diesel Electric - 550kW	1 or 2 cars	90 seated 94 standing 2 wheelchair	96 km/h	6%	40 m	N/A	31.24 m	3.00 m	3.91 m	0.584 m (low floor) 0.999 m (high floor)	2 bi-parting sliding plug	1.435 m	55 t	0.90 m/s^2	1.00 m/s^2	2.00 m/s^2	Good	
40	Colorado Railcar Single-Level DMU	Low floor, DMU FRA Compliant	Las Vegas, Florida (SFRTA), 2004	Diesel-hydrodynamic	2 - 5 cars per train set	92 seated 162 standing	145 km/h	3.2%	76 m	610 m	25.91 m	3.05 m	4.54 m	1.300 m	1 2-leaf sliding	1.435 m	79 t	0.53 m/s^2	0.89 m/s^2	1.25 m/s^2	Poor	

APPENDIX C
SAMPLE BRT VEHICLES

NEW FLYER - INVERO BRT DE60iLF – BRTG

Length	Weight
18.3 m	31.3 t

Capacity

Seats	Standees
47	53

Floor Type

Low floor with rear riser

Doors

Variable: 3 curb side- 2 double stream, one entrance door & 2 street side,

Applications

Lane Transit – BRT
Cleveland - BRT

Fuel Options

Diesel, gasoline, CNG, LNG

Features

Fully configured for true BRT
Doors on left and right side
Patented modular design
Modern styling
Patented interior lighting system
Panoramic windows
Large rear window
Plug / slide doors
Two stage ramp at optional entrance door
Bicycles on board
Hybrid-electric drive system
Built to accommodate vehicle guidance and docking system

ADVANCED PUBLIC TRANSPORT SYSTEMS BV - PHILEAS 60 (18)

Length	Weight
18.0m	16.8 t

Capacity

Seats	Standees
30	91

Floor Type

Continuous low floor between drive axles

Doors

3 doors per side (either or both sides)

Applications

Eindhoven, Netherlands

Fuel Options

LPG with CNG, Diesel options NiMH batteries or flywheel energy storage

Features

Futuristic and innovative styling
Spacious, front axle under driver and rear axle under the motor
High comfort suspended seating
High quality passenger information, audible and visual systems
Electronic fare payment
Flexibility, large doors both sides
Electronic auto guidance to 50 mph (80kph) with magnetic markers
Automatic precision docking
All-wheel steering
Fully independent suspension
Environmentally friendly

ADVANCED PUBLIC TRANSPORT SYSTEMS BV - PHILEAS 80 (24)

Length	Weight
24.0m	21.7 t

Capacity

Seats	Standees
38	121

Floor Type

Continuous low floor between drive axles

Doors

4 doors per side (either or both sides)

Applications

Eindhoven, Netherlands

Fuel Options

LPG with CNG, Diesel options NiMH batteries or flywheel energy storage

Features

Futuristic and innovative styling
Spacious, front axle under driver and rear axle under the motor
High comfort suspended seating
High quality passenger information, audible and visual systems
Electronic fare payment
Flexibility, large doors both sides
Electronic auto guidance to 50 mph (80kph) with magnetic markers
Automatic precision docking
All-wheel steering
Fully independent suspension
Environmentally friendly

BOMBARDIER TVR

Length	Weight
24.5 m	25.5 t

Capacity

Seats	Standees
37	108

Floor Type

Low floor

Doors

4 doors on each side.

Applications

Caen, France
Nancy, France

Fuel Options

Overhead pantograph, overhead trolley wires, batteries, or a motor/alternator set.

Features

70km/h top speed
On a limited basis, be driven and steered on ordinary roads by the operator as if it were a long bus.
Vehicles can also be guided as if on rails when the centre guide wheels are lowered into a guide rail installed flush in the centre of the road line.

TRANSLOHR VEHICLE, LOHR INDUSTRIES

Length	Weight
18 – 39m	17.7 to 22.3 t

Capacity

Seats	Standees
32 (25m)	84 (25m)

Floor Type

Low floor

Doors

The vehicle can be fitted to provide doors on both sides.

Applications

Clermont-Ferrand

Fuel Options

Diesel-electric using a diesel automobile engine combined with an overhead electric catenaries

Features

Vehicle design features a "light design" with extensive use of aluminum to purportedly achieve a 30% reduction in weight compared to other competing vehicles
Reversible 2-cab configuration
67.6 km/h top speed

CIVIS, IRISBUS

Length	Weight
18.3 m	21.5 t

Capacity

Seats	Standees
46	60

Floor Type

Full interior continuous low floor

Doors

Total of 4; 2 wide double-stream, operator or passenger interior/exterior controls

Applications

Las Vegas, NV, USA
Rouen, Clermont-Ferrand,
Grenoble and Lyon in France

Fuel Options

Low Sulphur Diesel or Gasoline, Dual-mode, or All-Electric with trolley catenaries

Features

Innovative, modern styling, seating
High capacity air conditioning
Large windows and skylights
Stop visual annunciation
GPS, signal priority interface
Off-vehicle payment system
Doors on either or both sides
Brakes with ABS anti-lock, ASR anti-slip systems
Video surveillance of interior/doors
Colour cameras and mirrors for rear vision and surveillance
Optical image processing system - motoring guidance, precision dock

MODEL 60 – BRT, NABI

Length	Weight
18.3 M	19.5 t

Capacity

Seats	Standees
60	30

Floor Type

Step Low Floor, composite construction

Doors

3 doors, location, width, style selectable

Applications

Los Angeles - Metro Rapid, BRT

Fuel Options

CNG, Diesel

Features

Customer specified exterior style
Automatic passenger counter
Automatic stop announcement
Automatic vehicle monitoring
Auxiliary coolant heater
Front, side, rear destination sign
Heating and/or air conditioning,
Various passenger seating, layouts
Choice in passenger doors
Conventional public address
GPS/AVL system
On-board video surveillance
Disc brakes
Up to 2 left side doors

ARTICULATED AN 460 LF

Length	Weight
18.3 M	20.0 t

Capacity

Seats	Standees
68	?

Floor Type

Low Floor or Standard

Doors

2 or 3, extra-wide automatically operated

Applications

Boston MBTA

Fuel Options

Clean Diesel, CNG

Features

Seating arrangement to customer's specifications
Optional Reclining High Back Seats
Optional Overhead Luggage Racks
Individual Reading Lights
Individual air
Easy Access Ramp for Wheelchairs
Three optional passenger window configurations
Radio and antenna
Destination sign, electronic or curtain
Driver controls and dashboard are interchangeable

NEW FLYER INDUSTRIES D60LF & DE60LF

Length	Weight
18.3 M	Up to 21.5 t

Capacity

Seats	Standees
Up to 64	?

Floor Type
Low Floor at and between all doors

Doors
2 or 3, extra-wide automatically operated

Applications
Ottawa, Seattle, and many other locations

Fuel Options
Diesel, Natural Gas, Diesel-Electric Hybrid

Features
Seating arrangement to customer's specifications Air conditioning Easy Access Ramp for Wheelchairs Multiple propulsion options Designed for easy access maintenance Parts and materials interchangeable with other vehicles

APPENDIX D
SELF-POWERED RAIL CAR FACT SHEET

This fact sheet describes 78 SPRCs currently operating or on order for North American urban transit applications.[1]

Characteristics of SPRC's in North American Urban Transit Systems[2]	Category 1				Category 2		Category 3
	Budd/AMF Remanufactured 1950's RDC (Dallas)	United Transit Systems Single Level DMU (Triangle Transit)	Colorado Rail Car Single Level DMU (Fla.Tri-Rail)	Colorado Rail Car Bi Level DMU (Fla.Tri-Rail)	Bombardier Talent BR643 (Ottawa)	Siemens VT 642 Desiro (Calif)	Stadler GTW 2/6 (NJTransit)
First Year of Service	1997	2008	2005	2005	2002	2007	2004
Fleet Size	13	28	1	1	3	12	20
Seating Capacity	96	80	92	188	135	139	90
Standees[3]	NA	160	148	75	150	90	94
Total Passenger Capacity	NA	240	240	263	285	229	184
Approx. Capital Cost (millions)	$1.80	$2.64	$2.90	$3.90	$3.90	$4.22	$3.60
Total Horsepower	600	950	1200	1200	845	864	753
Engines	2	2	2	2	2	2	1
Drive System	Diesel Mechanical	Diesel Mechanical	Diesel Mechanical	Diesel Mechanical	Diesel Mechanical	Diesel Mechanical	Diesel Electric
Weight (tons)	68	65	74	82	80	75	58
Length (feet)	85	85	85	85	160	136.81	103
Height (feet)	14.6	14.5	15.1	18.0	13.2	12.5	12.8
Min. Curve Radius (feet)	NA	300	250	250	328		132
Tons/Seat	0.7	0.8	0.8	0.4	0.6	0.5	0.6
Capital Cost/Seat	$18,800	$33,000	$31,500	$20,700	$28,900	$30,400	$40,000
Capital Cost/Passenger	NA	$11,000	$12,000	$14,900	$13,700	$18,400	$19,600
HP/Ton	9	15	16	15	11	12	13
Low or Midlevel Boarding?	No	No	No	Yes	Yes	Yes	Yes
Approximate Noise and Vibration	Medium	Medium/Low	Medium/Low	Medium/Low	Low	Low	Low

[1] In addition to the new urban applications, various North American railways also use vintage Budd RDC equipment to operate limited leisure-market services in Alaska, Canada, Syracuse NY and Cape May NJ.
[2] Compiled by David Nelson of KKO and Associates, LLC (Please submit updates/corrections to dnelson@kko.com)
[3] Standee capacity figures are based on vendor reports which may vary in the perception of acceptable levels of passenger crowding

Typology of North American SPRC Vehicles and Applications		
Category	**Description**	**North American Examples**
Category 1: FRA Compliant Car	Relatively heavy cars primarily designed for safe and unrestricted use on the nation's conventional railroad network sharing track with other trains including freight, commuter rail and Amtrak operations. Complies with all regulations stipulated by Federal Railroad Administration (FRA) for operation on the US conventional railroad network. Trinity Railway Express linking Fort Worth with Dallas uses a fleet of 13 rebuilt vintage Budd RDC's originally constructed in the 1950's. South Florida RTA's Tri Rail service linking Miami, Fort Lauderdale and West Palm Beach has ordered two new DMU's from Colorado Rail Car. The Colorado Rail Car offering is the first Category 1: SPRC built in more than 40 years. North Carolina's Triangle Transit Authority has ordered 28 cars for its Raleigh-Durham service opening in 2008.	*Texas' Trinity Railway Express*  *South Florida RTA's Tri-Rail car* 
Category 2: Non FRA Compliant Railway Car	Similar to Category 1 units but generally too lightly built to meet FRA standards relating to crashworthiness. Generally used to provide service in the 15 to 30 minute headway regime on a railway shared with conventional railroad operations. In North America, the conventional railway operations are limited to the overnight period to minimize risk of catastrophic collision between the light passenger car and heavier conventional rail equipment. In Europe where conventional railway vehicles are not as heavy as in North America, the discrepancy in weight and strength between the Category 2 car and other vehicles is not a concern and the SPRC operates in mixed traffic with other freight and intercity services. Ottawa's O-Train uses three sets of married triplets manufactured in Europe by Bombardier in 2001. California's North County Transportation District has ordered a fleet of 12 German cars from Siemens for its SPRINTER service.	*Ottawa's O-Train*  *California's Oceanside SPRINTER car* 

Typology of North American SPRC Vehicles and Applications		
Category	**Description**	**North American Examples**
Category 3: Diesel Light Rail Vehicle	Diesel Light Rail Vehicles (DLRVs) are shorter, lighter, articulated cars designed to negotiate tight turns required for street running trolley operations. Both domestically and overseas, the Category 3 car is used in similar settings to the Category 2 car except that the passenger service generally extends onto a street running segment where track geometry requires a DLRV to negotiate tight curves New Jersey's RiverLINE uses a fleet of 20 articulated DLRV's built by Stadler in Switzerland.	*New Jersey's RiverLINE - GTW 2/6* 

APPENDIX E
LRT VS BRT PRE-ENGINEERING
COMPARATIVE COST ESTIMATE

OTTAWA NS LRT PROJECT
LRT vs BRT PRE-ENGINEERING COMPARATIVE COST ESTIMATE

	LRT - Electric Light Rail Vehicles		BRT - Bus Rapid Transit with Special Artic Buses	
Daily Ridership	**65,000**	**80,000**	**65,000**	**80,000**
Infrastructure Capital Cost	**$594,539,954**	**$594,539,954**	**$505,417,692**	**$505,417,692**
(Excludes design and other soft costs)	**118%**	**118%**	85%	85%
	45 vehicles	57 vehicles	85 vehicles	106 vehicles
Vehicle Capital Cost	**$195,985,000**	**$247,981,000**	**$110,500,000**	**$137,800,000**
	177%	**180%**	56%	56%
Total Capital	**$790,524,954**	**$842,520,954**	**$615,917,692**	**$643,217,692**
% of BRT Capital Cost	**128%**	**131%**		
			222,907 annual veh hrs	274,347 annual veh hrs
Yearly Operating & Maintenance Cost		Based on Ottawa historical	$24,517,564	$30,175,464
	177,655 annual veh hrs	218,652 annual veh hrs		
Based on RTD & SEPTA	$22,742,514	$27,990,786	**$25,747,121**	**$31,688,764**
	88%	88%	113%	113%
Savings from Coupling LRT Cars in PeakPeriods	**($2,376,854)**	**($2,925,359)**	0	0
Total Yearly Op. & Mtce Costs	**$20,365,659**	**$25,065,427**		
% of BRT Yearly Op. and Mtce Cost	**83%**	**83%**		
Life Cycle Refurbishment Costs :				
Refurbish Rail Vehicles at 25 Years	$48,996,250	$61,995,250		
Replace Buses every 15 Years (Residual value deducted)			$257,465,000	$321,074,000
Rehab Maintenance Facility at 25 Years	$10,005,250	$10,005,250	$9,475,000	$9,475,000
Rehab Stations at 25 Years	$22,825,000	$22,825,000	$20,675,000	$20,675,000
Rehab Park & Ride Lots at 25 Years	$2,000,000	$2,000,000	$2,000,000	$2,000,000
Rehab Busway at 25 Years			$25,500,000	$25,500,000
Rehab Trackbed (not required for 50 years)	$0			
Sub Total 50 Year Life Cycle Costs	**$83,826,500**	**$96,825,500**	**$315,115,000**	**$378,724,000**
% of BRT 50 Year Refurbishment Costs	**27%**	**26%**		

APPENDIX F
SAMPLE CALCULATIONS FROM OPERATING HOURS MODEL (LRT AND BRT)

Sample Calculations From Operating Hours Model (LRT and BRT)

			Number of Boardings	
Daily ridership			70,000	
	Proportion of Daily Ridership			
Peak Period Ridership - AM	30%		21,000	Multiply daily ridership by proportion
Peak Period Ridership - PM	30%		21,000	Multiply daily ridership by proportion
Midday Ridership	30%		21,000	Multiply daily ridership by proportion
Evening & Early Morning Ridership	10%		7,000	Multiply daily ridership by proportion
	Proportion of Peak Period Ridership			
Peak Hour Ridership - AM	50%		10,500	Multiply peak period ridership by proportion
Peak Hour Ridership - PM	50%		10,500	Multiply peak period ridership by proportion
	Proportion of Peak Hour Ridership		Number of Passengers	
Peak Hour Peak Point Ridership - AM	40%		4,200	Multiply peak hour ridership by proportion
Peak Hour Peak Point Ridership - PM	30%		3,150	Multiply peak hour ridership by proportion

	LRT	BRT	
Seated Capacity	70	50	
Standing Capacity	150	60	
Proportion of Standing Capacity for Design	50%	50%	
Design Capacity	145	80	Seated capacity + proportion of standing capacity
Trips Per Hour - AM	29	53	Peak hour peak point ridership / design capacity
Trips Per Hour - PM	22	39	Peak hour peak point ridership / design capacity
Service Headway - AM (min)	2.1	1.1	60 minutes / trips per hour
Service Headway - PM (min)	2.8	1.5	60 minutes / trips per hour
Average Operating Speed (kph)	50	50	
Facility Length (km)	30	30	
Round Trip Travel Time (min)	72	72	2 x Facility length / average operating speed
Layover Time (min)	5	5	
Total Round Trip Travel Time (min)	82	82	Round trip travel time including layover
Vehicles Required for Service - AM	39.6	71.8	Total travel time / service headway
Vehicles Required for Service - PM	29.7	53.8	Total travel time / service headway
Vehicle Spare Ratio	10%	12%	
Total Vehicles Required - AM	**43.5**	**80.4**	Vehicles required for service + spares
Total Vehicles Required - PM	**32.7**	**60.3**	Vehicles required for service + spares

Continued on Next Page

Sample From Operating Hours Model (Continued)

Midday & Early Evening & Saturday/Sunday Daytime Headway Factor	1.5	2.5	Factor to increase average peak service headway
Midday & Early Evening & Saturday/Sunday Daytime Headway	3.6	3.3	Average peak service headway x headway factor
Midday & Early Evening & Saturday/Sunday Daytime Vehicles in Service	22.6	24.6	Total travel time / headway
Late Evening & Saturday/Sunday Morning & Evening Headway Factor	3	5	Factor to increase average peak service headway
Late Evening & Saturday/Sunday Morning & Evening Headway	7.3	6.7	Average peak service headway x headway factor
Late Evening & Saturday/Sunday Morning & Evening Vehicles in Service	11.3	12.3	Total travel time / headway
AM Peak Period Hours	3	3	Number of hours of operation in time period
PM Peak Period Hours	3	3	Number of hours of operation in time period
Midday & Early Evening Hours	9	9	Number of hours of operation in time period
Late Evening Hours	3	3	Number of hours of operation in time period
Saturday Daytime Hours	9	9	Number of hours of operation in time period
Saturday Morning & Evening Hours	9	9	Number of hours of operation in time period
Sunday Daytime Hours	6	6	Number of hours of operation in time period
Sunday Morning & Evening Hours	12	12	Number of hours of operation in time period
AM Peak Period Vehicle Hours	118.8	215.3	Number of Vehicles x Hours of Operation
PM Peak Period Vehicle Hours	89.1	161.4	Number of Vehicles x Hours of Operation
Midday & Early Evening Vehicle Hours	203.6	221.4	Number of Vehicles x Hours of Operation
Late Evening Vehicle Hours	33.9	36.9	Number of Vehicles x Hours of Operation
Total Weekday Vehicle Hours	445.3	635.0	Total Weekday Vehicle Hours
Saturday Daytime Vehicle Hours	203.6	221.4	Number of Vehicles x Hours of Operation
Saturday Morning & Evening Vehicle Hours	101.8	110.7	Number of Vehicles x Hours of Operation
Total Saturday Vehicle Hours	305.4	332.1	Total Saturday Vehicle Hours
Sunday Daytime Hours	135.7	147.6	Number of Vehicles x Hours of Operation
Sunday Morning & Evening Vehicle Hours	135.7	147.6	Number of Vehicles x Hours of Operation
Total Sunday Vehicle Hours	271.4	295.2	Total Sunday Vehicle Hours
Total Annual Vehicle Hours	**144,665.0**	**195,293.3**	252 x Weekday + 52 x Saturday + 61 x Sunday
AM Peak Period Round Trips	86.9	157.5	Hours of operation / headway
PM Peak Period Round Trips	65.2	118.1	Hours of operation / headway
Midday & Early Evening Round Trips	149.0	162.0	Hours of operation / headway
Late Evening Round Trips	24.8	27.0	Hours of operation / headway
Total Weekday Round Trips	325.9	464.6	Total Weekday Round Trips
Saturday Daytime Round Trips	149.0	162.0	Hours of operation / headway
Saturday Morning & Evening Round Trips	74.5	81.0	Hours of operation / headway
Total Saturday Round Trips	223.4	243.0	Total Saturday Round Trips
Sunday Daytime Round Trips	99.3	108.0	Hours of operation / headway
Sunday Morning & Evening Round Trips	99.3	108.0	Hours of operation / headway
Total Sunday Round Trips	198.6	216.0	Total Sunday Round Trips
Total Annual Round Trips	105,852.4	142,897.5	252 x Weekday + 52 x Saturday + 61 x Sunday
AM Peak Period Vehicle Kilometres	5,214	9,450	Round trips x round trip distance
PM Peak Period Vehicle Kilometres	3,910	7,088	Round trips x round trip distance
Midday & Early Evening Vehicle Kilometres	8,938	9,720	Round trips x round trip distance
Late Evening Vehicle Kilometres	1,490	1,620	Round trips x round trip distance
Total Weekday Vehicle Kilometres	19,552	27,878	Total Weekday Vehicle Kilometres
Saturday Daytime Vehicle Kilometres	8,938	9,720	Round trips x round trip distance
Saturday Morning & Evening Vehicle Kilometres	4,469	4,860	Round trips x round trip distance
Total Saturday Vehicle Kilometres	13,407	14,580	Total Saturday Vehicle Kilometres
Sunday Daytime Vehicle Kilometres	5,959	6,480	Round trips x round trip distance
Sunday Morning & Evening Vehicle Kilometres	5,959	6,480	Round trips x round trip distance
Total Sunday Vehicle Kilometres	11,917	12,960	Total Sunday Vehicle Kilometres
Total Annual Vehicle Kilometres	**6,351,145**	**8,573,850**	252 x Weekday + 52 x Saturday + 61 x Sunday