APPENDIX A

LRT AND BRT TECHNOLOGY OPTIONS

A1 LRT AND BRT TECHNOLOGY OPTIONS

A1.1 This Appendix provides a brief overview of BRT and LRT technologies that could be considered for the A-Line route and sets out information on the different vehicles and system characteristics. References are made to relevant examples from North America as well as from other cities and regions from around the world.

FIGURE A.1 LRT - LYON, FRANCE

FIGURE A.2 BRT - NANTES, FRANCE

A1.2 An overview of the different system and vehicle characteristics is shown in Table A.1 and Table A.2.

TABLE A.1 COMPARISON OF TYPICAL SYSTEM CHARACTERISTICS

	Bus Rapid Transit	**Light Rail Transit**
Typical Mode of Operation	Driver, line of sight	Driver, line of sight
Level of Segregation	Bus/Transit only lane	Priority/ Segregated
Typical Alignment Width (straight sections)	3.5 metres / direction	3.25 metres / direction
Maximum Gradient	12%	6% desirable 8% maximum (10% *1)
Typical Route Lengths	5 - 20 km	10 - 30 km
Peak Headway	2 to 10 min	2 to 10 min
Passenger Capacity of System (/ hr / dir) (*2)	500 – 3,500	1,200 – 15,000
Traffic Management/ Signalling	Conventional traffic signals (*3) / priority	Conventional traffic signals (*3) / priority
Stop/Station Spacing	400 - 1,500 m	400 - 1,500 m
Maintenance and Storage Facilities	Off/On Line	On line
Capital Cost/km (excluding vehicles)	$3.5 to $15 m	$50 to $80 m

Notes

1 Gradients above 8% require additional traction motors and enhanced braking capability.

2 Capacity based upon peak headway and vehicle capacities detailed in Table A.2.

3 Conventional traffic signals may incorporate Bus/LRT-Only aspects to permit Bus/LRT movements when other traffic movements are halted.

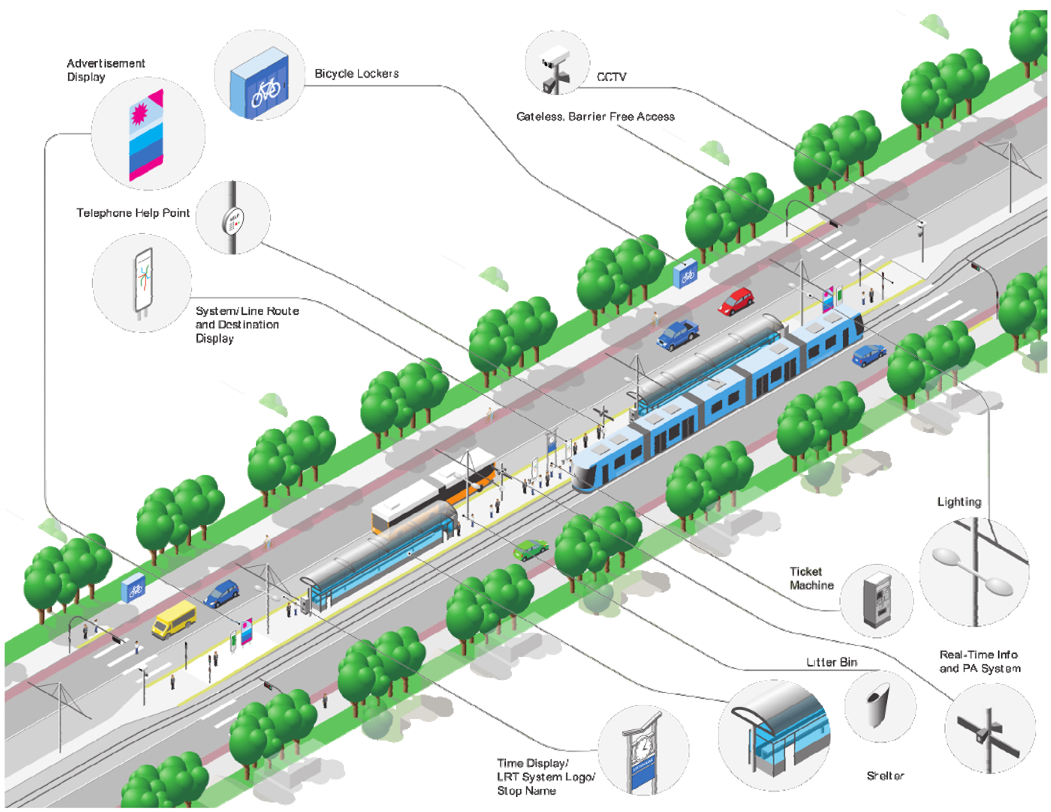
TABLE A.2 COMPARISON OF TYPICAL VEHICLE CHARACTERISTICS

	Bus Rapid Transit	Light Rail Transit
Typical Vehicle Length (single car or articulated unit)	12.5 m (rigid) / 18.5 m (articulated)	30 – 45 m (modular articulated units)
Maximum Speed	80 km /h	80 km /h
Capacity per car (approximate - will vary with manufacturer)	80 / 120	200 - 250 (30 m vehicle)
Seats	29 / 62	60 - 90
Accessibility	Level Boarding	Level Boarding
Vehicle Life	12 – 15 years	30 years
Capital Cost	\$0.45 / \$1.5 m	\$4 to \$7 m

Typical Stop Facilities

A1.3 Figure A.3 shows a typical LRT stop and illustrates a range of stop facilities which would usually be provided for LRT and BRT rapid transit systems.

FIGURE A.3 TYPICAL LRT STOP FACILITIES



Bus Rapid Transit (BRT)

Introduction

A1.4 BRT systems aim to emulate LRT levels of capacity, speed and service quality, but at lower cost, by using bus technology. Improvements in the level of service and capacity over conventional bus services are achieved by adding a series of measures to improve the performance and quality of service, offering faster and more reliable journey times and improved facilities for passengers. BRT is usually implemented on higher demand corridors where conventional bus services cannot meet the passenger demand or where the interactions between buses and other traffic result in poor reliability and variable bus journey times.

FIGURE A.4 BRT - EUGENE, USA

A1.5 The key components of high quality BRT are:

- Dedicated right-of-way including:

  Bus only streets

  Bus only designated lanes within existing roadway
- Priority at intersections
- Modern, low floor vehicles
- Multiple door boarding
- Off-bus ticketing

- Distinctive branding
- Stops/Shelters
- ITS/Real-time information

BRT Right of Way

A1.6 A number of different BRT design approaches can be used. Wider stop spacing and the implementation of greater segregation and priority over general traffic are designed to provide faster and more reliable services. Routes are usually provided with priority at signalled intersections.

A1.7 Segregation from other road users can take the form of dedicated lanes on existing roadway, dedicated unguided roadway and dedicated guided roadway.

A1.8 A segregated unguided bus-only road can have raised platforms at stops aligned such that the vehicles can run straight into the stop without needing to manoeuvre close to a curb. This reduces the stepping distance for boarding and alighting passengers.

FIGURE A.5 GUIDED BRT - ESSEN, GERMANY

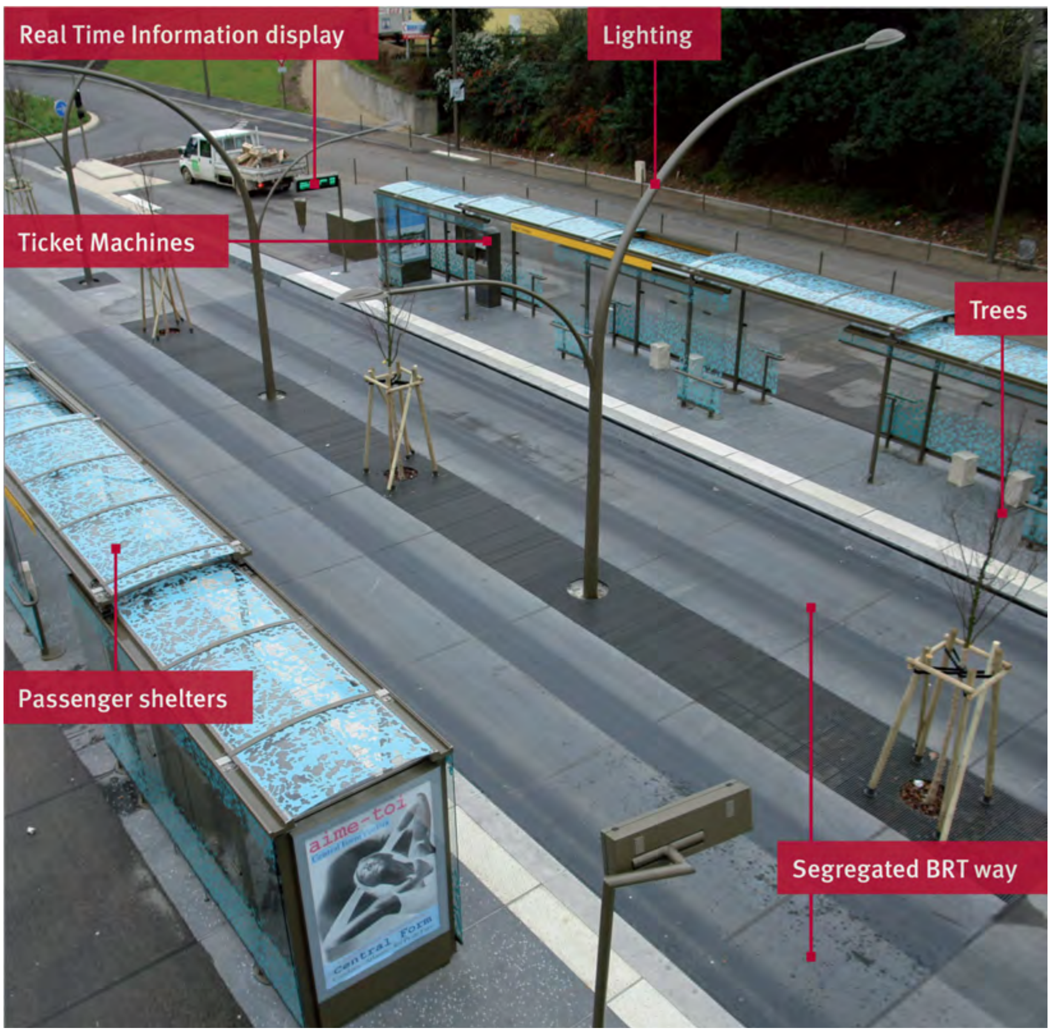
A1.9 Where routes are fully segregated, buses can use forms of guidance such as a curb or magnetic induction to improve ride quality, speed and to reduce the width of the alignment. Guidance can also be used to aid the vehicles' docking with stops to minimize passenger stepping distances.

A1.10 Curb guidance systems use a raised curb along with guide wheels attached to the vehicle's steered wheels. Curb guided systems can be constructed with conventional highway pavements and precast concrete curbs, but for the highest ride quality a precast concrete specialized guideway system is required. In areas with poor ground conditions this may need piled foundations, adding to the system cost.

BRT Stops

A1.11 Most modern BRT stops feature infrastructure comprising a low platform for near-level boarding, together with a shelter and other equipment made up from a 'kit of parts'. The BRT stop in Nantes in Figure A.6 demonstrates a number of these features.

FIGURE A.6 BRT STOP – NANTES, FRANCE



A1.12 Typically the ‘kit of parts’ includes: shelter, seats, information, ticketing and garbage cans. Key interchanges and busy stops will be more fully equipped than less busy suburban stops, but the ‘kit of parts’ approach maintains a continuity of branding /visual image across the BRT route/ network.

A1.13 Shelters are normally high quality, often specially designed to provide identity along with corridor branding, and may feature a combination or all of the following: real time information, CCTV, help / information points and ticket machines.

BRT Vehicles

A1.14 BRT systems can operate with a range of vehicle types, usually based on standard buses. Some BRT vehicles aim to adopt elements of LRT styling to differentiate them from conventional bus services. An example is the Wrightbus BRT vehicle, pictured in Figure A.7, which is currently operating on conventional bus services in a number of UK cities, and a hybrid diesel-electric version has also been supplied for use in Las Vegas. Vehicles may be rigid, or single or double articulated to suit the proposed style of service and the passenger capacities required. Double deck rigid buses are also used. To limit dwell times at stops buses may have multiple doors to speed boarding and alighting. Off bus ticketing is often employed to ensure that the service dwell time at stops are minimized to help ensure consistent end to end journey times.

FIGURE A.7 WRIGHTBUS BRT VEHICLE

Operating Characteristics

A1.15 BRT services operate with a greater level of segregation and priority over other road users using dedicated infrastructure. This segregation provides faster and more reliable journey times compared to regular bus services. This in turn can allow the operation of higher frequency services. Bus priority can be provided through signalled intersections. An automatic vehicle location system can also be used to monitor each vehicle's performance against a timetable, with higher priority given to late-running vehicles, and lower or no priority to vehicles which are on or ahead of time. This helps to maintain service frequency and reduce vehicle bunching. Services can be as frequent as every 2 to 3 minutes in the peaks, although the maximum frequency which can be achieved will in part be dependent on the effect the level of BRT priority may have on intersection capacity for general traffic.

A1.16 Routes are operated by drivers on line of sight and controlled by intersection signalling.

Network Form

A1.17 BRT may operate as a single end-to-end service on a particular corridor, or a radial BRT route may be operated by a number of services from other neighbourhoods which join the route along its length (trunk and branch operation). Segregated radial routes can be combined with on-street operation in central areas (where routes may be shared with other bus services and with general traffic, and lesser levels of bus priority can be provided) to provide a wider BRT network.

A1.18 Stop spacing is often closer to urban LRT systems, typically 400 - 1,500 metres.

Usage Worldwide

A1.19 BRT systems have been developed world wide, the majority of systems being implemented in Europe, Australia, South and North America. Systems featuring extensive segregation include the Transmilenio in Bogota, the Ottawa Busway system and the O-Bahn Guided Busways in Essen and Adelaide. More recent examples featuring a mix of BRT components include Eugene OR, Los Angeles CA, Cleveland OH and Nantes, France.

Community Integration and Environment

A1.20 BRT systems introduced in urban environments can be integrated with the surrounding communities and public realm. The introduction of BRT lanes provides an opportunity to upgrade the streetscape, rationalize parking and loading areas and improving pedestrian environments. This can also include improvements to landscaping, and the introduction of public art.

A1.21 The introduction of upgraded signals to provide BRT priority also enables enhanced pedestrian crossing facilities to be provided.

FIGURE A.8 BRT - EUGENE, USA

A1.22 The strengths and weaknesses of BRT as a rapid transit mode are summarised below.

Strengths

- Faster, more reliable journey times and closer peak headways than conventional services are possible, when on segregated rights of way. (In urban areas, BRT benefits are constrained by running in street - main benefits are higher quality buses and BRT stops similar to the existing B-Line Express.)
- Higher total capacity than conventional bus services on street
- Distinctive route/brand identity and amenities such as real-time information, raise the profile of the system compared with conventional bus services
- Total capacity can be varied with rigid or articulated vehicles in conjunction with peak headway
- Relatively cost effective to implement and operate
- Can be developed and implemented relatively quickly
- Service routing flexibility to overcome disruption during incidents/breakdowns/segregated route blockages

Weaknesses

- Vehicles may not be able to overtake each other easily (depending on infrastructure)
- Total capacity limited by articulated vehicle and frequency
- Curb-guided systems may be subject to operational difficulties during periods of ice / snow in an environment such as Hamilton's.
- Segregated / guided route may be vulnerable to disruption during incidents.
- Lower user perception than LRT

Light Rail Transit (LRT)

Introduction

A1.23 Light Rail Transit (LRT) features vehicles with steel wheels running on steel rails, usually to standard railway gauge (1.435m). LRT systems are electrically powered from overhead lines and use either single cars operating singly or in multiple, or multi-section articulated units. LRT systems run primarily on segregated alignments and modern low floor systems are integrated into urban areas to provide easy and direct connections for passengers and local communities.

FIGURE A.9 LRT - HOUSTON, USA

A1.24 The key components of high quality LRT are:

- Flexible alignment types-designed to maximize segregated surface level operation
- Alignments can be grade-separated, elevated or in tunnel
- Modern systems feature low floor vehicles with multiple double doors for easy level boarding and alighting

- Stops feature shelters, information, system branding, CCTV/help points, ITS/real time information, off-vehicle ticketing
- Platforms are 300-350mm “raised curbs” easily designed into urban areas
- Articulated vehicles, steel wheel on steel rail, with track flush with road surface
- Vehicles electrically powered via overhead lines supported by poles or building fittings. Alternative designs with no wires being developed.
- Flexible vehicle design, modular construction, can be operated in 2-4 car coupled units
- Priority at intersections

FIGURE A.10 LRT - MONTPELLIER, FRANCE

A1.25 Light Rail can accommodate tighter curves – typically 25m minimum radius – and steeper gradients – up to 8%, or more with additional traction motors and enhanced braking – than conventional rail, and is thus much better suited for use in built-up urban areas.

A1.26 LRT can run on a range of alignment types, including shared running with other traffic, operation through pedestrianized areas and on segregated alignments, most commonly at grade, but they can be grade-separated either on elevated structures or in tunnel.

It is a standard design assumption for all modern LRT systems that the proportion of segregated alignment should be maximized to capture journey time and reliability benefits.

A1.27 Shared running with other traffic can be used in central areas. LRT can also, subject to appropriate speed limits and operational procedures, run in pedestrian areas where other vehicles are not permitted.

A1.28 On-street LRT alignments which are segregated from other vehicular traffic allow for greater LRT priority and reliability. On street segregation does not need to be fenced, thereby avoiding the spatial requirements and visual intrusion of barriers. Segregated reserves can run either in the centre or at the side of the road, as in the Montpellier and Marseille examples illustrated in Figure A.11 and Figure A.12.

FIGURE A.11 LRT TRACK IN CENTRE OF ROAD – MONTPELLIER, FRANCE

A1.29 LRT can also run on fully segregated alignments, typically running parallel to rail lines or on disused rail alignments.

A1.30 Systems are driven on sight, controlled by traffic signals, usually with dedicated LRT-only aspects. A degree of priority is usually given to LRT over other traffic. On high speed sections, some systems operate under railway-type signalling.

A1.31 Stops are typically spaced 400-1500m metres apart, with the wider spacings in suburban areas.

A1.32 Many early LRT systems in North America are routed on either old rail corridors or major arterial roads (e.g., Edmonton, Sacramento, Calgary, Salt Lake City), and generally used high-floor vehicles with systems designed to be highly segregated and with larger scale stop infrastructure.

FIGURE A.12 LRT AND STOP IN SIDE RESERVE – MARSEILLE, FRANCE

A1.33 However, most new LRT systems now use low floor cars that improve accessibility and allow level boarding from simple, slightly raised platforms. This form of LRT is similar to modern European tram systems and has become the standard for new systems worldwide. It allows LRT to be introduced into existing urban areas, particularly European city centres with relatively narrow streets. This is the form of LRT discussed in this section.

Stop Infrastructure

A1.34 LRT stop infrastructure comprises a low platform for level boarding, together with a shelter and other equipment made up from a 'kit of parts'. Typically these include: shelter, seats, information, ticketing and garbage cans. Key interchanges and busy stops will be more fully equipped than less busy suburban stops, but the 'kit of parts' approach maintains a continuity of branding /visual image across the LRT route/network.

A1.35 Shelters are normally high quality, often specially designed to provide identity along with corridor branding, and may feature a combination or all of the following: real time information, CCTV, passenger announcement, help / information points and ticket machines.

Light Rail Transit Vehicles

A1.36 New LRT systems use low floor vehicles with a floor level typically 300-350mm above rail level. Allied to the use of low platforms, this provides level boarding.

A1.37 Manufacturers offer a variety of lengths and styles of articulated LRVs ranging from 30 to 70 metres in length; the shorter versions can be coupled to provide 2-4 car trains where required.

A1.38 LRT vehicle manufacturers have developed modular solutions to provide a variety of vehicle configurations, whilst being based on standard components. Many recently supplied vehicles are based on a standard vehicle approximately 30 metres long made up of two identical vehicle end sections with driving cabs and one or three intermediate sections. The standard vehicle width is nominally 2.65 metres. This width allows a central corridor to be provided with double seats on either side (2+2 seating), as illustrated in Figure A.13. Narrower vehicles are sometimes provided with 2+2 seating, but these results in a narrow central corridor or narrow seats, and it is more usual to provide 2+1 seating on narrower vehicles. Manufacturers provide as standard reduced widths down to 2.2m.

FIGURE A.13 VEHICLE INTERIOR WITH 2+2 SEATING - MONTPELLIER, FRANCE

A1.39 An example of the modular design of vehicles is that of the Citadis vehicle manufactured by Alstom. Figure A.14 shows the modular vehicle concept, and some of the options which can be supplied. Figure A.14 also shows alternative vehicle end designs which can be applied to the standard vehicle body and Figure A.15 shows the external and internal layouts of two typical light rail vehicles.

A1.40 Within these body configurations a range of internal layouts can be provided, with space for seated and standing passengers and at least one wheelchair space per vehicle.

FIGURE A.14 CITADIS MODULAR VEHICLE OPTIONS AND ALTERNATIVE VEHICLE END DESIGNS

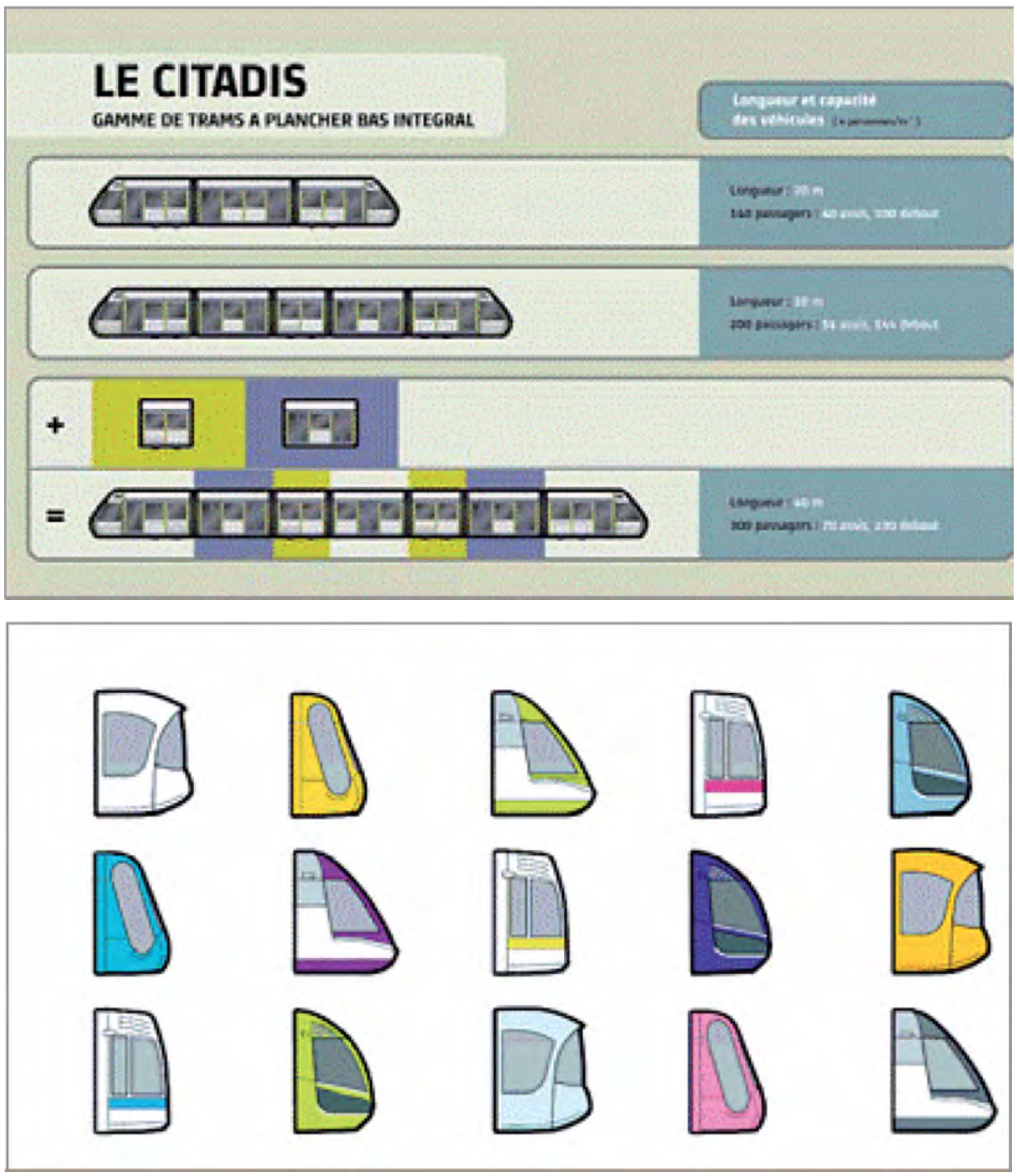
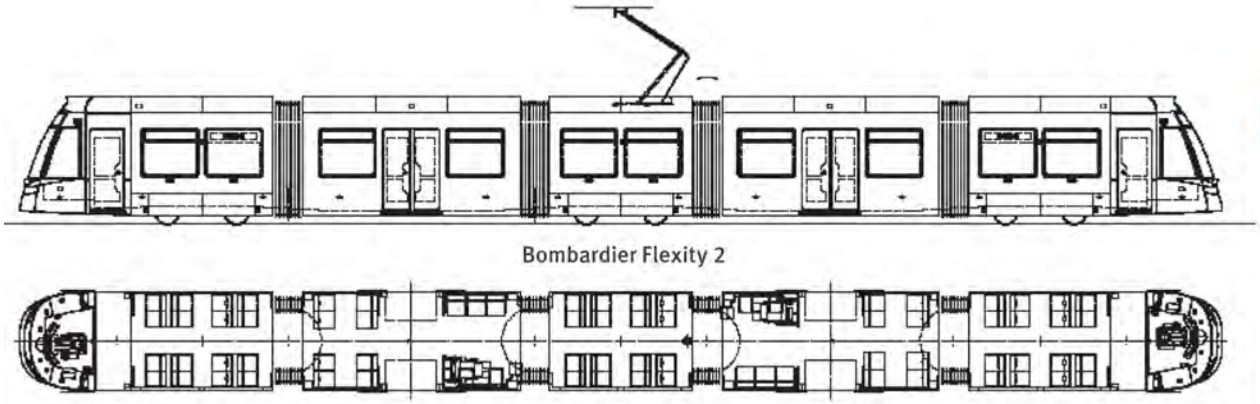
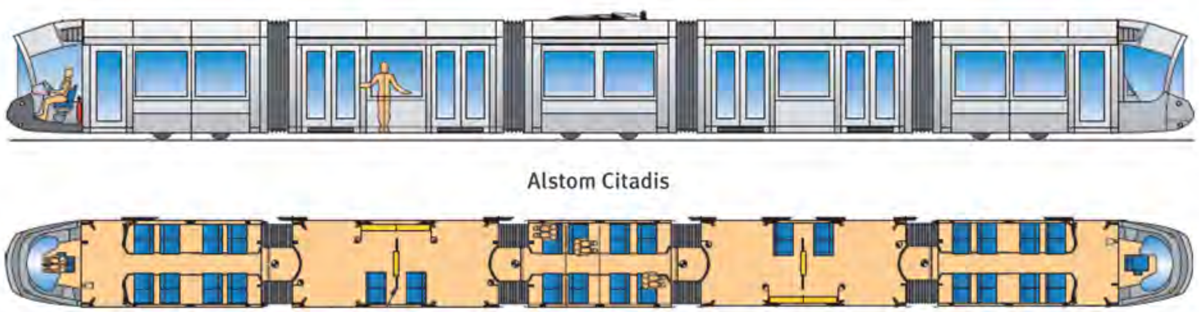


FIGURE A.15 EXTERNAL AND INTERNAL LAYOUTS OF 5-MODULE LRVS



Bombardier Flexity 2

Flexity 2	
Length	32.2 m
Width	2.65 m
Maximum speed	70 km/h
Seated passengers (incl. tip up seats)	74
Standing passengers (4 pass/m²)	148
Total Passengers	222



Alstom Citadis

Citadis	
Length	32.4 m
Width	2.4 m
Maximum speed	70 km/h
Seated passengers	56
Standing passengers (4 pass/m²)	144
Total Passengers	200

Operating Characteristics

A1.41 Priority is provided at the majority of road intersections providing routes with consistent, shorter journey times relative to operation in mixed traffic. Peak headway can be as low as every 2 minutes, subject to local pedestrian, cycle and traffic needs.

A1.42 Vehicles are driver operated and controlled on line of sight using the road signalling at intersections.

A1.43 Vehicles are electrically powered from a single overhead line, with return current passing through the running rails. Systems can also be powered by proprietary overhead free systems, which currently have a cost premium, and are generally restricted to fairly short lengths of route.

Community Integration and Environment

A1.44 On street LRT systems can be integrated with the surrounding communities and urban realm. Segregated LRT lines can use a grass track finish to minimise visual intrusion. In a Hamilton context this may be an appropriate approach for LRT in central medians, subject to any requirements in relation to snow clearing.

A1.45 The introduction or upgrading of signals to provide LRT priority also enables enhanced pedestrian crossing facilities to be provided.

FIGURE A.16 DOWNTOWN LRT - PORTLAND, USA

FIGURE A.17 7-SECTION MODULAR LRV - BORDEAUX, FRANCE

Network Form

A1.46 LRT may operate as a single end-to-end service on a particular corridor, or a radial or cross-city LRT route may be provided with 2 (or more) branches at its outer end(s) to increase the areas served. Segregated radial routes can be combined with on-street operation in central areas (where routes may be shared with bus services or with limited other traffic, and lesser levels of priority can be provided) to provide a wider LRT network and improve access to key destinations.

A1.47 Modern low floor LRT systems can be designed in urban areas to link people and places with stops integrated into the communities they serve. Stop spacing is typically around 800m within suburban areas, and closer in central areas where there is a range of destinations to be served. In outer areas where the urban density is lower, stop spacing may increase to around 1.5km. In such areas walk-in catchments are reduced and a greater proportion of demand will be from park and ride and feeder bus services.

Usage Worldwide

A1.48 In the last 20 years a significant number of modern light rail systems have been implemented worldwide with hundreds of system operating. The technologies used have also been implemented on a significant number of older systems to reinvigorate and improve the service provision.

A1.49 The strengths and weaknesses of LRT as a rapid transit mode are summarised below

Strengths

- Flexible alignment design criteria allow LRT to be fully integrated with urban realm
- Higher capacity than bus and BRT
- Low Noise
- Zero emissions at the point of use
- Segregation and priority can be used to provide reliable journey times
- Provision of fixed infrastructure, demonstrates a commitment to the provision of high quality public transport services
- Can act as a catalyst for wider urban development

Weaknesses

- Relatively high capital cost (including need for extensive utilities diversions in many cases)
- Significant disruption during construction
- Total capacity limited by vehicle and frequency
- Speed and travel time benefits require priority over other traffic
- On street rail-based route vulnerable to disruption during incidents.
- Fixed rails limit flexibility.

FIGURE A.18 LRT - HOUSTON, USA

A-Line-Specific Constraints

A1.50 The A-Line route has to climb the Niagara Escarpment. There are three existing road routes up the Escarpment in the vicinity of the A-Line corridor, with gradients of up to 11%.

A1.51 The two steeper of these routes are used by bus services at present, and so all three routes should also be usable by BRT.

A1.52 Conventional LRVs, typically with 2/3 of the axles motored, are capable of negotiating gradients up to around 8%. With all axles motored gradients of 10% can be achieved. Corresponding improvements to the braking systems are also required for use on steeper gradients.

A1.53 However, the gradient capabilities quoted by vehicle manufacturers are usually based on ascending and descending somewhat shorter gradients than would occur at the Escarpment. Any alignment solution here, whether at 6%, 8% or 10%, will involve an extended run compared with slopes typically encountered elsewhere, and there may be a risk of overheating of traction and/or braking equipment. As the Escarpment route options are developed, the proposed alignments should be discussed with prospective vehicle suppliers in order to ensure that suitable vehicles can be provided for the A-Line.

A1.54 Similarly the geometric constraints associated with some of the route options, particularly the combinations of gradient, horizontal track curvature and vertical track curvature, may be significantly more onerous than when each of these elements is encountered individually. Manufacturers provide little generic guidance on the capabilities of vehicles in such circumstances, so again, critical sections of the alignment should be discussed with vehicle suppliers at an early stage.

APPENDIX B

FACILITIES TO BE PROVIDED AT MOBILITY HUBS

B1 FACILITIES TO BE PROVIDED AT MOBILITY HUBS

The Design of a Mobility Hub	
At the station	• Clear, easy, convenient access to stations for all • Good signage • Good lighting • Weather-protected, heated waiting areas • Washrooms/change rooms • Bicycle stations • Real-time service information • Service kiosks with refreshments, papers, etc. • Local destination map/information • Internet connectivity • Place-making and public art • Travellers' aid/telephones • Virtual workplace • Safe environmental design • Car-share program
Around the station	• Transit plaza • Transit links to nearby destinations • Convenience shopping (dry cleaning, flowers, etc.) • Daycare • Pleasant open space • Cultural, educational, entertainment, institutional uses • Convenient connections between modes (weather-protected pedestrian walkways, shuttle buses) • Cafés/restaurants • Grocery store • Personal services (banking, etc.) • High Occupancy Vehicle preferred parking • Plug-ins for electric vehicles • Facilities for delivery of goods

Source – Mobility Hubs – Development of a Regional Transportation Plan for the Greater Toronto and Hamilton Area - Green Paper 2, Metrolinx (2008)

APPENDIX C

ILLUSTRATIVE A-LINE DESIGN WORKBOOK 1 ALIGNMENTS

RAPIDTransit moving HAMILTON forward

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Light Rail Transit

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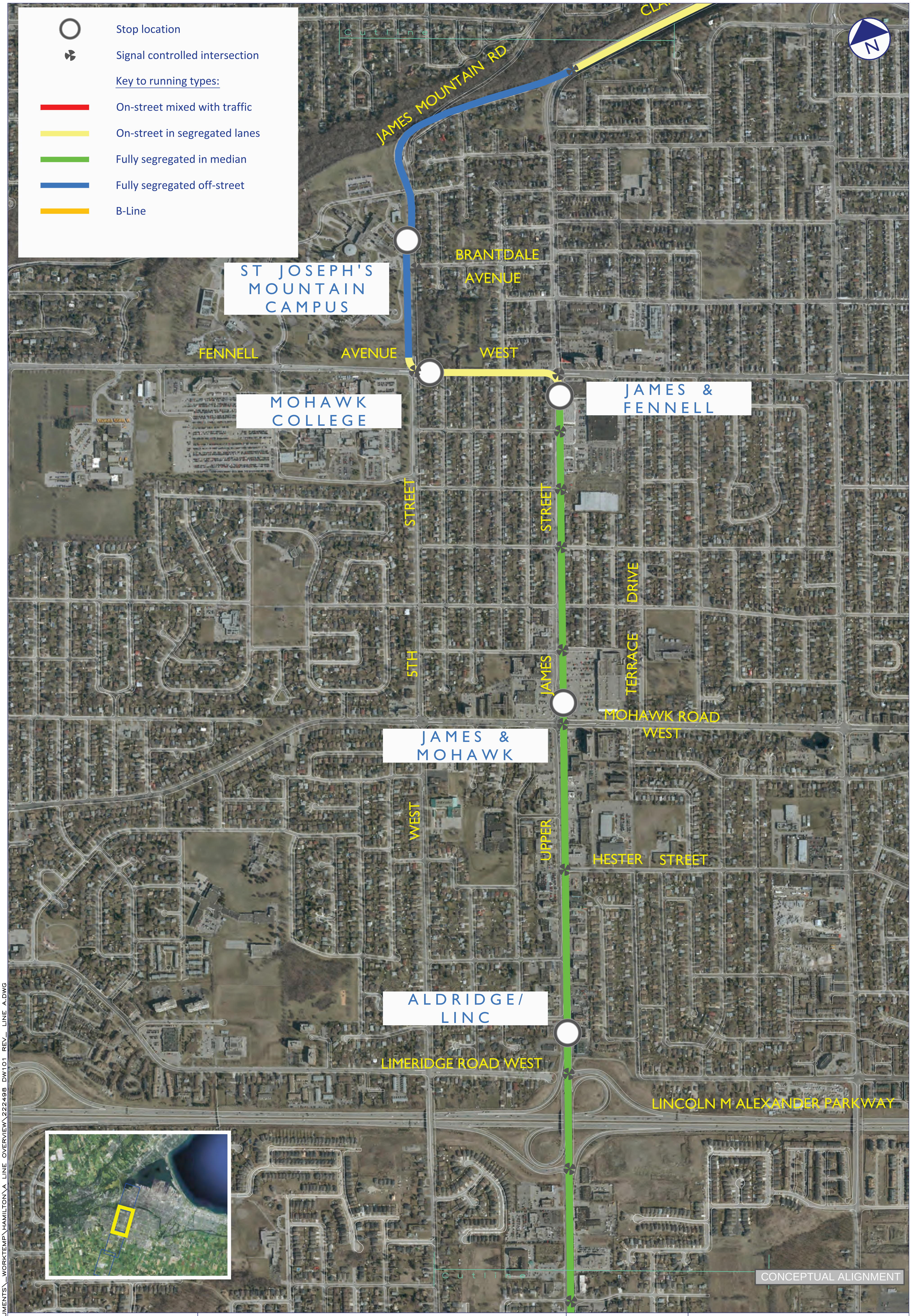

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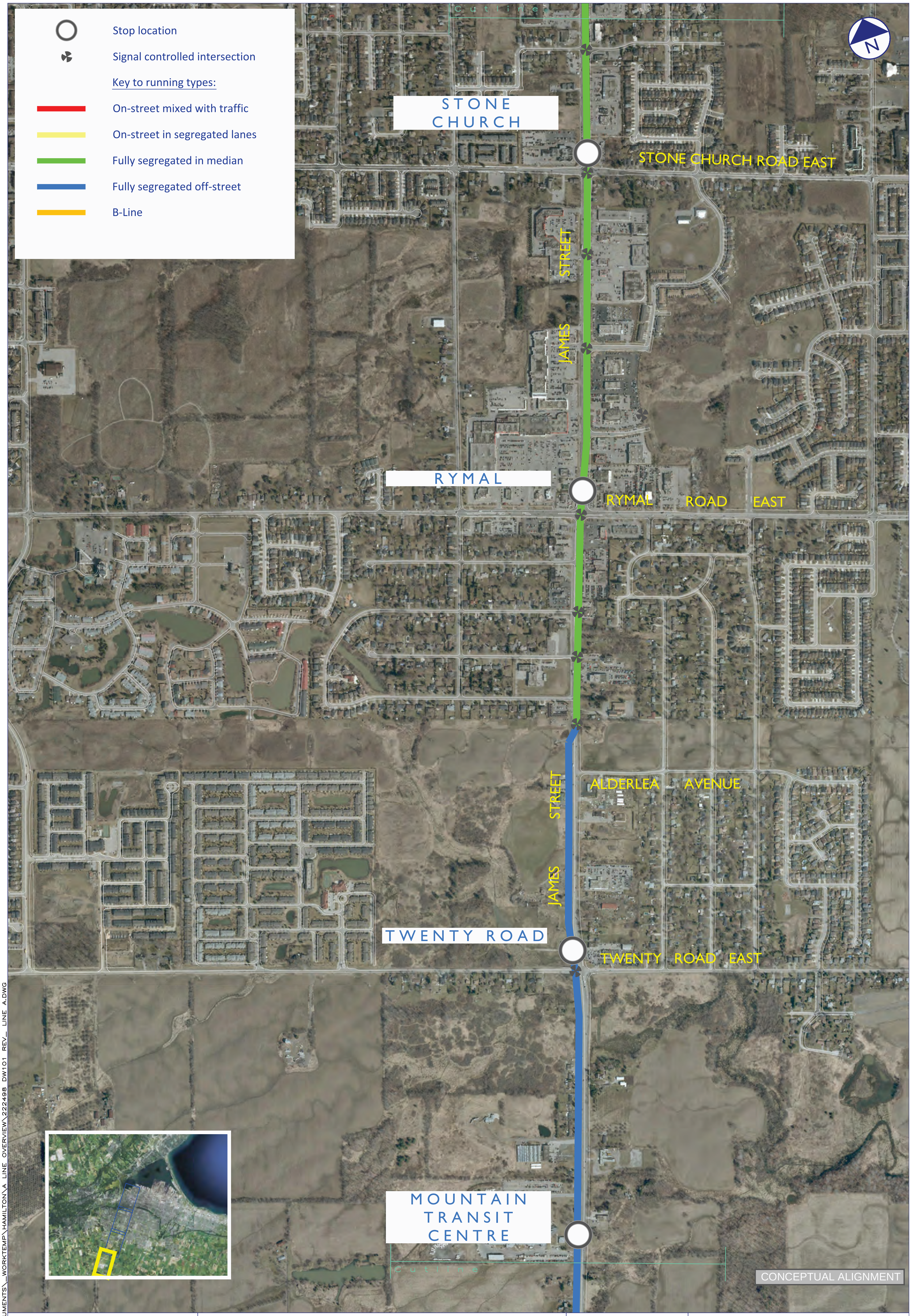

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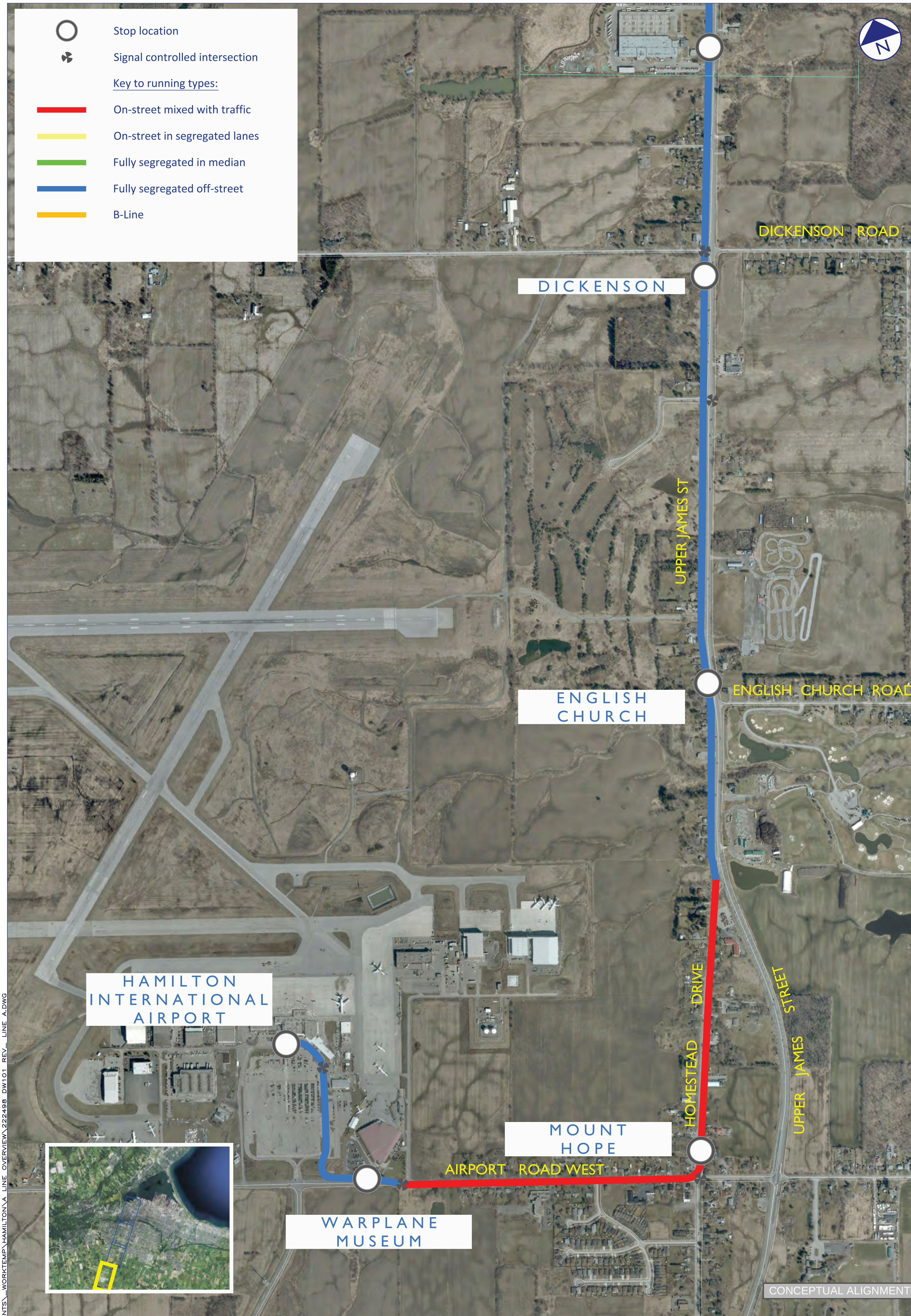

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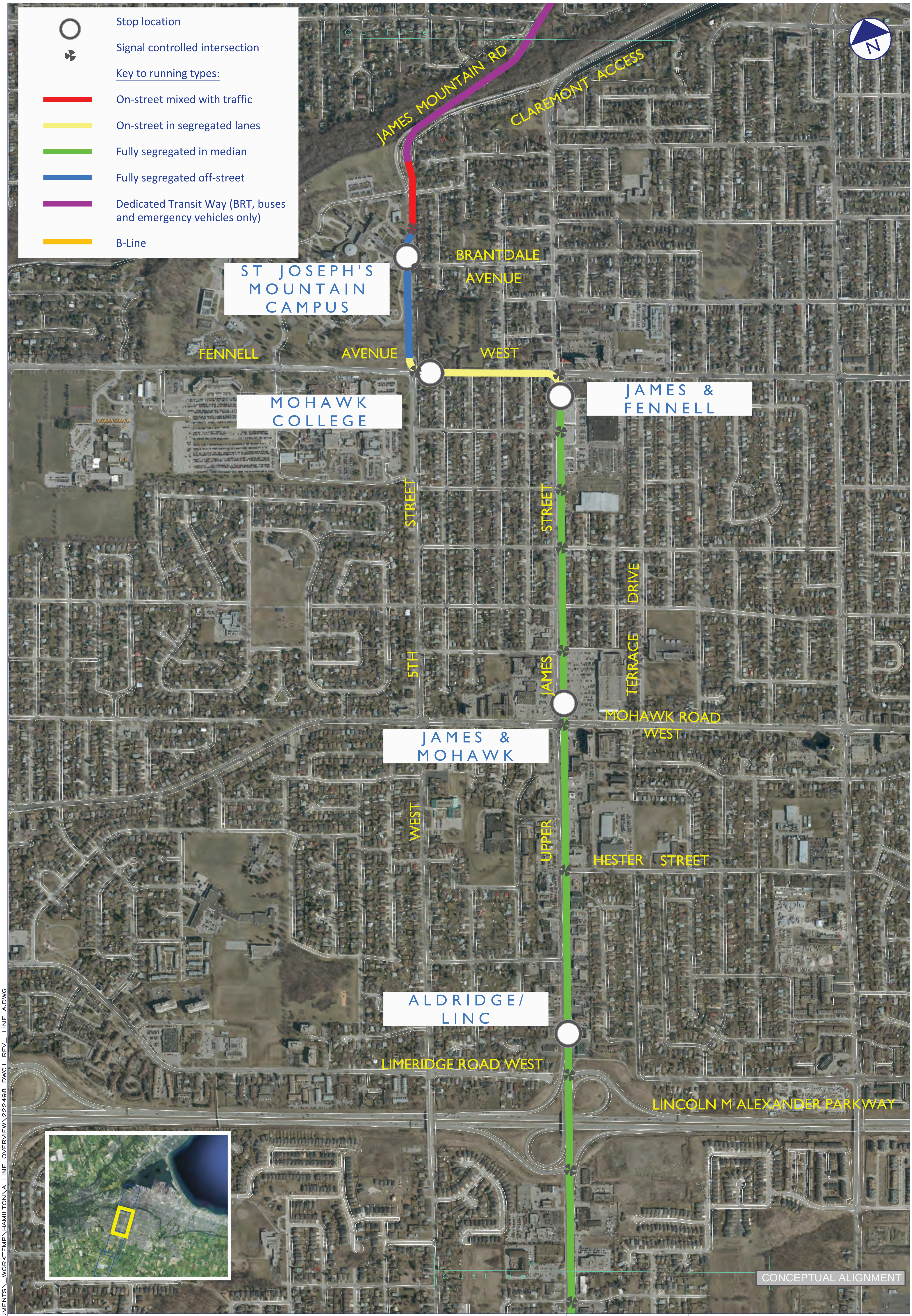

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RAPIDTransit moving HAMILTON forward

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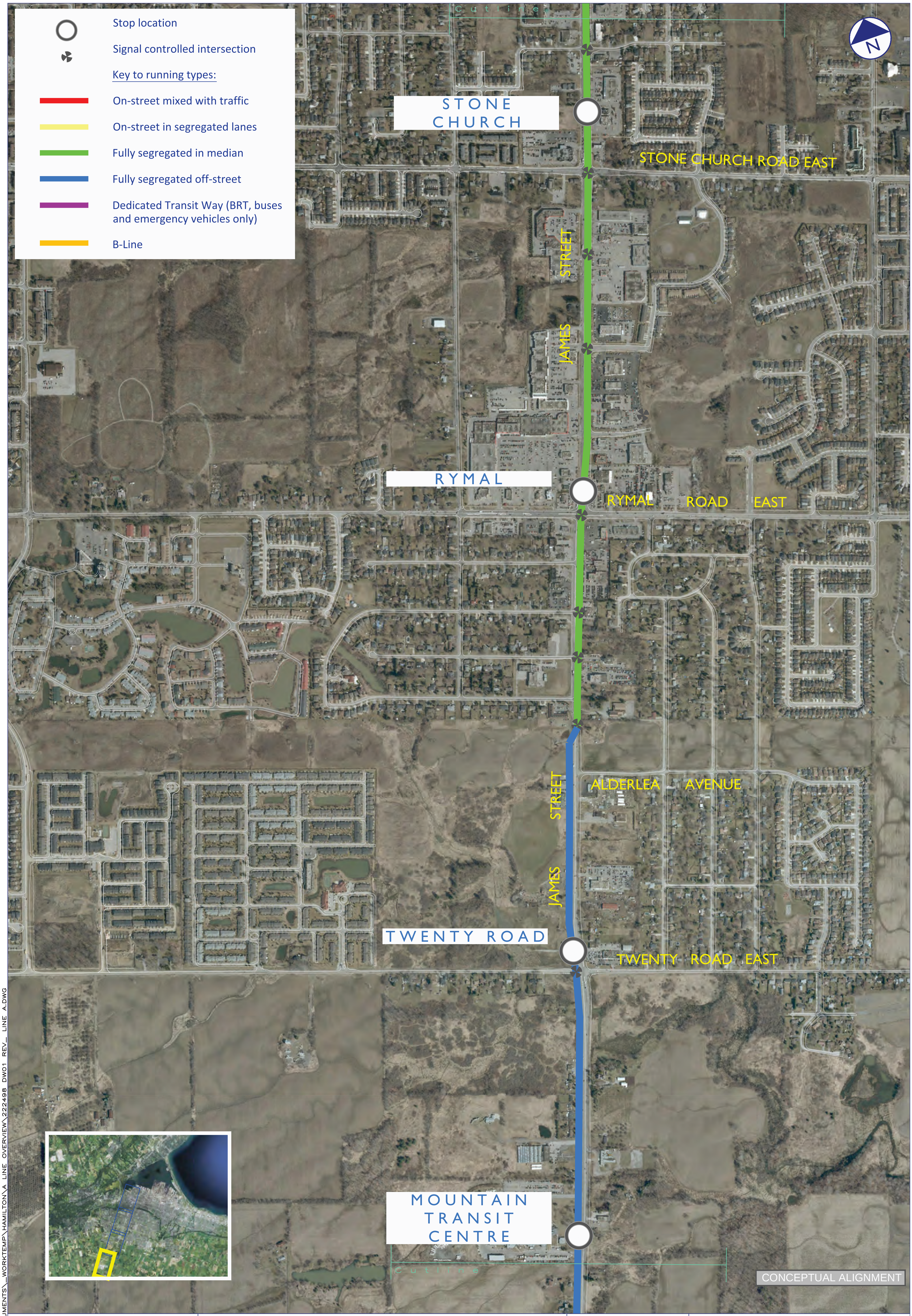

RAPIDTransit moving HAMILTON forward

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