Hamilton Public Works

Rapid Transit Office
City of Hamilton Public Works

Light Rail Technology
Overview & Analysis

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Rapid Transit
MOVING HAMILTON FORWARD

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1. Project Overview

In many rapid transit discussions, technical meetings and public forums, questions regarding light rail transit (LRT) technologies commonly arise. Many wonder if the vehicles and infrastructure can meet the various challenges surrounding Hamilton's particular geographical and street level constraints, while others are interested in how they operate and what design considerations are required. This analysis provides an investigation of the technologies associated with rapid transit infrastructure and aims to:

- Examine light rail infrastructure, rolling stock, power systems and operational aspects
- Provide an in-depth investigation of potential LRT technical challenges in Hamilton
- Investigate technologies that may be able to address Hamilton's geography and planning constraints
- Investigate the operating and maintenance costs of these technologies
- Examine the historical context of light rail technologies in Hamilton
- Develop a basis to guide further planning and design research
- Develop recommendations and considerations for further planning and construction efforts

This analysis is divided into the following sections:

1. **Light Rail Transit Defined:** provides a working definition of LRT in order for the reader to fully understand how the City of Hamilton interprets the technology.
2. **Technical Specifications:** discusses the three main components of an LRT system, that of infrastructure, rolling stock and fixed equipment. Understanding theses components and their interaction is vital to making decisions regarding light rail technologies.
3. **Technological Challenges:** describes potential issues that may arise in the design of an LRT system for Hamilton and outlines mitigation strategies.
4. **Operating and Maintenance Financial Considerations:** an analysis of LRT technologies should include an understanding of the costs that they represent over their lifecycle.
5. **Potential Market for Made-in-Hamilton Light Rail Vehicles and Systems:** Hamilton can capitalize on its manufacturing expertise to attract LRV development locally.
6. **Historical Context of Rapid Transit in Hamilton:** chronicles the development of Rapid Transit in Hamilton since the 1960s in order for decision makers and the public to learn from previous attempts to establish a rapid transit system in the city.

2. Light Rail Transit (LRT) Defined

The term light rail transit has been used to describe electric rail systems since the 1970s, with no formal definition until 1989, when the transportation research board (TRB) developed a standard definition (Boorse, 2000). Hamilton will use a modified definition based on that of the TRB which defines LRT as:

A lightweight metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive right-of-way at street level. These vehicles are usually powered by overhead electrical wires, and offer a frequent, fast, reliable, comfortable and high quality service that is environmentally sustainable.

LRT is often identified by its right-of-way and vehicle weight and size. When compared with a regional railway or metro, the system is lighter in terms of actual system weight. However, when compared with modern low-floor trains, LRT is heavier because the vehicles are usually wider or there are two to three vehicles coupled together. The terms 'heavy' or 'light' do not solely refer to weight, but also to the flexibility of a system to deal with different types of right-of-way and to the ability to be integrated into a variety or urban streetscapes (Topp, 1999).

The flexibility in the definition of LRT alludes to its significant advantages. The ability to be operated as a traditional tram with a shared right-of-way in outer parts of the city and also as a tram on a separate railroad with segregated or exclusive right-of-way in the city centre, makes LRT one of the most flexible transit systems available. Because of the flexibility of LRT systems, they can be easily integrated with the existing streetscape. Designated LRT stations or stops can provide easy access, convenient stay and personal safety, something that is considered completely different when compared with underground systems (Topp, 1999). LRT is also designed to operate in a variety of environments. These can include, but are not limited to, on-street, highway medians, railroad right-of-way (operating or abandoned), pedestrian malls, underground or aerial structures and even in the beds of unused canals. This characteristic is one that clearly distinguishes LRT from other types of rail modes. The design flexibility makes LRT one of the most readily adaptable, permanent systems and thus, is often less costly to build and operate than other fixed-railway nodes (Boorse, 2000). An overview of several light rail transit system types can be found in Appendix A.

3. Technical Specifications

Despite the numerous categories and types of LRT systems, they are comprised of the following basic elements: (1) Rolling Stock: a fleet of railcars that are used to carry passengers along the track ways, and designed so that they can be combined to make longer trains; (2) Infrastructure: comprised of the track ways, stations and maintenance/storage yards, including any associated structures such as tunnels, bridges and subsurface infrastructure; (3) Fixed Equipment: includes the operations centre, power supply infrastructure, signals and communications facilities as well as road-side infrastructure (Boorse, 2000).

3.1 Rolling Stock

The rolling stock refers to the cab of the train, its wheel assembly (or bogies) and its electrical systems, including the electricity collecting arm (or pantograph). In order to discuss the rolling stock it is necessary to define a set of average system specifications which will form the base train used throughout this analysis.

3.1.1 Proposed System Specifications

It is anticipated that Hamilton LRT vehicles and track systems will most closely resemble systems operating in Portland, Oregon, Minneapolis, Minnesota and Lyon, France which use trains supplied by Siemens, Bombardier and Alstom, respectively. While their design varies between systems, Hamilton's trains will potentially resemble the average specifications outlined in table 1.

Table 1: LRT System Specifications

Specification	Value
Track Gauge (Standard)	**1.435 m**
Vehicle Weight (Empty, average)	**41 000 kg**
Vehicle Weight (Full, average)	**63 000 kg**
Single Vehicle Height (with pantograph)	**3.9 m**
Single Vehicle Length (average) (constrained by intersection spacing)	**28 m**
Single Vehicle Width	**2.65 m**
Horizontal Vehicle Clearance (total)	**1.0 m**
Vertical Vehicle Clearance (minimum)	**4.1 m**
Ballast/Track Bed Depth (average)	**0.74 m**
Passengers (seated/standing, total)	**60/130, 190**

These specifications are visualized in figure 1 and the vehicles they are based on are shown in figure 2. Hamilton's size, proposed right of way, required headway and length of vehicle, indicate that the Bombardier Flexity Outlook, Siemens Combino Plus and Alstom Citadis are three likely candidates for the rolling stock in the Hamilton light rail system. All these trains are 100% low floor and powered by overhead electrical wires.

Figure 1: System Specifications Diagram outlining average LRT vehicle measurements

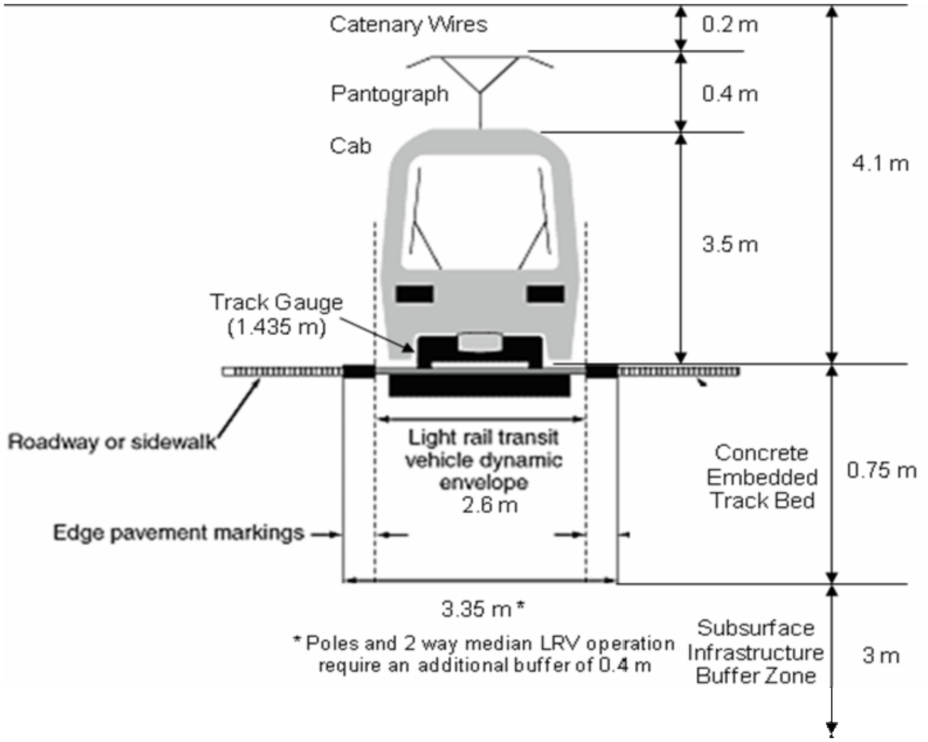


Figure 2: Vehicles from various manufacturers which the study was based on

Flexity Outlook & Flexity Swift (Bombardier)  Brussels, Geneva, Minneapolis, Cologne, Porto	**Citadis (Altsom)**  Lyon, Montepellier, Stockholm
S70 (Siemens)  Calgary, Portland, Charlotte	**Combino Plus (Siemens)**  Amsterdam, Lisbon

(Photos courtesy of Bombardier, Siemens and Alstom)

LRT vehicles vary in the look of their fiberglass exterior and inner arrangement of seating and handles; however, in general, most trains are 2.65 m in width and weigh 45000 Kg. Any weight differences are generally due to differences in pantograph design and HVAC systems. Vehicle length can very depending on the ridership requirements, length of city blocks, stop spacing, desired headway and power system requirements. Lengths generally vary from 28 m to 40 m. Given Hamilton's city block length, headway requirements and ridership projections, the cab will most likely be 28 m in length.

Light Rail Vehicles (LRVs) can have an extensive range of features including those that accommodate disabled passengers, bicycle racks, passenger information systems and environmental control systems. Various vehicle components include: air conditioning, heating, power collectors and ground cables, electrical connection equipment, entertainment/information systems, train event recorders, door systems, locomotive parts, wheels, brake systems, vehicle propulsion control systems, circuit breakers, rail shock and impact recorders, lighting, door indicators, and fare management systems. Many of these vehicle components are required for the train to operate efficiently and safely (Light Rail Now, 2005). Other components can be added based on regulations and municipal needs. These can include access ramps, bridge plates, folding steps and low-floor platforms. Some systems also have bike hooks for commuters to store their bikes while using the trains, as shown in figure 4 (APTA, 2003).

Figure 3: LRT Vehicle interior photos with areas for special needs seating

(Photos courtesy of Alstom, Siemens and Bombardier)

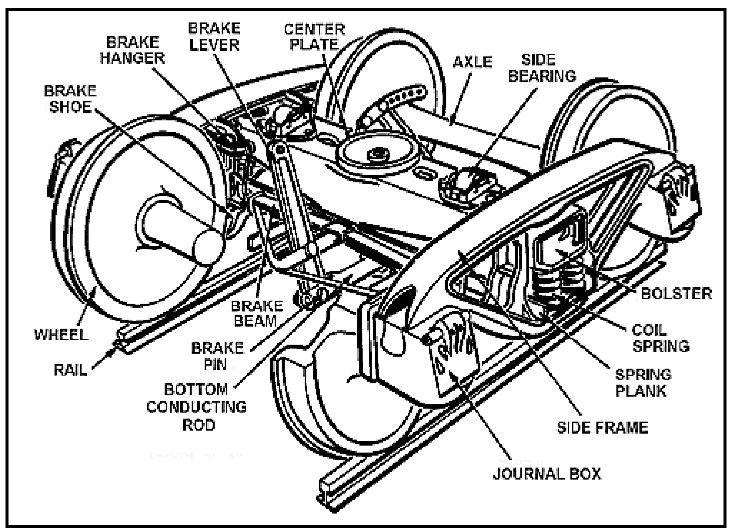
Figure 4: Interior Bike Rack Storage in various LRT vehicles

(Photos courtesy of Alstom, Bombardier and Siemens)

3.1.2 Bogies

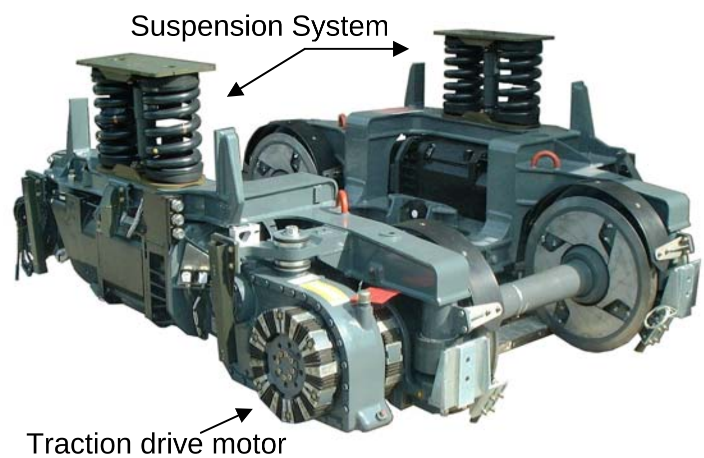
The bogie assembly is not usually visible in a LRV as it is in a traditional rail vehicle, but it is an essential component of the rolling stock. Bogies attach to the cab and connect the wheels, axels, breaks, suspension and traction drive motors to the train body. Their main function is to allow the train to run, stop and absorb shock stably through straight and curved track sections. They also absorb vibration and minimize centrifugal force as the train curves. A common bogie configuration includes two axels and four wheels, usually level with the train floor. However, today's modern low floor vehicles can have a floor height that is lower than the bogies (Okamoto, 1999).

Figure 5: Typical Bogie Configuration (Okamoto, 1999)



Modern LRT bogies shown in figure 6 include the traction drive motor, spring suspension and the ability to support low floor train configurations running on embedded track. Passenger comfort and vibration and noise mitigation are important considerations in bogie design. Some low floor bogies have no axels in order to achieve low floor design specifications. In addition, modern bogie designs attempt to eliminate intrusion into the cab as much as possible. This is especially important for suspension design, which occupies the highest point of the bogie (Okamoto, 1999).

Figure 6: Modern Low Floor Vehicle Bogie Design (Courtesy of Bombardier)



3.1.3 Pantograph

The pantograph is an adjustable, spring loaded, ‘z’ shaped arm that collects current from the electric power supply system used to power the traction drive motors. The current is collected from the contact shoe at the top of the pantograph, which is pushed against the electrical supply wire by the pantograph arm. This shoe can be from made from various materials, including carbon based contacts, and is subject to wear from being in constant contact with the supply wire. Depending on the elevation of the ground, the pantograph can respond to slight variations and can be fully raised or lowered when passing under most bridges. Most manufacturers have minimum operating height requirements, which may present a problem with the under-crossing of some Hamilton bridges (see section 4.1.3 for an analysis of under-bridge crossings at the King Street pedestrian bridge and the James Street TH&B bridge).

3.2 Infrastructure

Light Rail Transit infrastructure includes all the supporting structures which allow the train to travel on the street and interact with passengers. This includes the road base, trackway, tunnels, bridges, stations and maintenance facility. In addition, the infrastructure under the roadway may also be affected by the addition of rail infrastructure and require relocation.

3.2.1 Road and Track Base

Typical railway tracks consist of two parallel steel rails, secured to crossbeams (or crossties) which maintain a constant distance between the two rails, referred to as the gauge. The track is laid on a bed of crushed stone (ballast) or a concrete foundation. This configuration, along with the supporting roadway, is referred to as the rail right of way. The subsurface concrete support is used to ensure that the tracks remain in place securely, withstanding temperature changes. Other road building techniques are used to ensure that the weight of the train is supported by the road bed.

Ballasted Track is a traditional method for constructing rail in which the running rails are laid on a stone base or concrete slab. The base or ballast is required to support the weight of the train, distribute its load, ensure that the rails do not buckle and provide water absorption and drainage. The crossties, which are concrete or wooden planks, are laid on top of the ballast, in between the tracks. They are used to maintain the track gauge, which is the measure of the spacing between the tracks. The accepted standard gauge is 1.435 m.

In older cities, concrete or asphalt was poured over ballasted tracks to provide a street level system which could blend with road asphalt and cobblestone. Most modern LRT systems employ techniques that embed tracks into concrete rather than use traditional track construction. This helps to eliminate buckling and irregularities in the track bed due to freeze and thaw conditions. These tracks are usually in the form of a girder rail, which allows the track to be easily embedded in the street surface. As shown in the image on the left, these rails have an additional groove that prevents the wheel from making contact with the concrete.

Direct Fixation Track is comprised of a concrete base and no ties or ballast. The rails are mounted onto fasteners and attached to a concrete deck as shown in figure 1.

Resilient Embedded Track is a design method commonly used in a city's central business district for grade operation on city streets. Resilient track is the hardest to track style to design and build, as the track is fully embedded in a concrete base and requires design elements to control for water drainage, vibration and corrosion. In order to mitigate the issues associated with embedded track, resilient materials are required to balance and distribute the loads, reduce vibration impact and electrically resist stray currents from the track, when it is used as a return path for the power supply circuit (see section 3.3.1). Figure 2 provides an example of a typical embedded track design; however, other designs also exist. Figure 3 shows and example, from Bordeaux, France, of an embedded track before the second concrete pour.

Figure 7: Direct Fixation Embedded Track (TCRP, 2002)

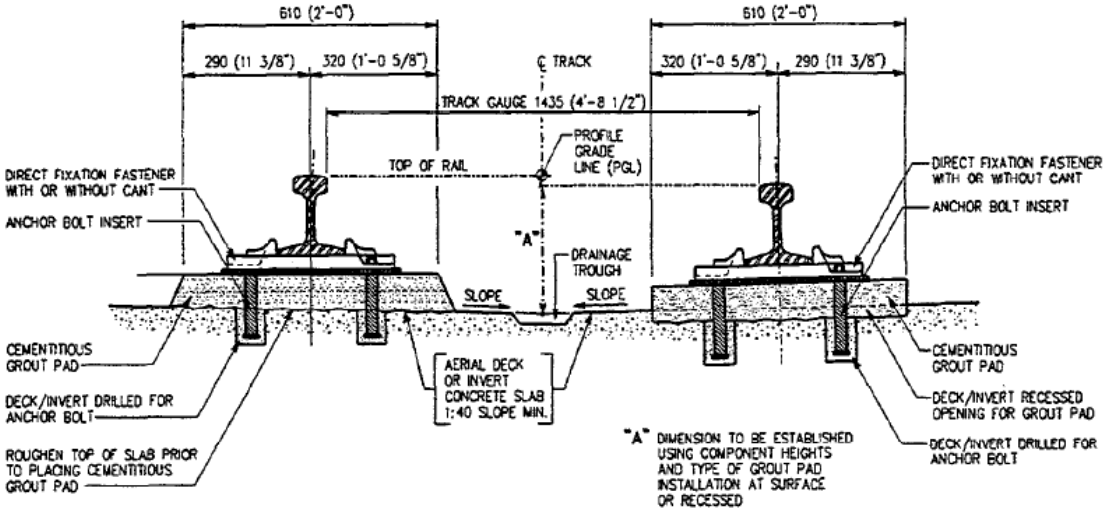


Figure 8: Two Pour Concrete Embedded Track with 2 individual rail troughs (TCRP, 2002)

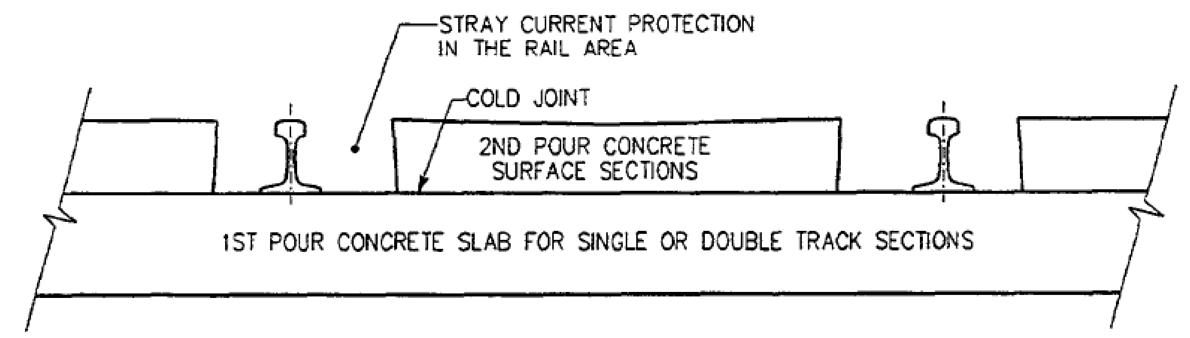


Figure 9: Typical Embedded Track with embedded third rail during construction in Bordeaux, France

(Photo courtesy of Alstom)

3.2.1.1 Insulating and Resilient Materials

These are a collection of polymers and other materials that distribute load, mitigate vibration and are electrically resistant, to protect surrounding infrastructure from train loads and stray electrical currents. Figure 10 and 11 illustrate the various ways in which these materials are used. Figure 10 illustrates the trough filling technique, in which the track is embedded. Part (a) demonstrates the electrical isolation surface insulation technique and in part (b), polymers are used as part of the fill to help mitigate vibration. Figure 5 provides an overview as to how these components are designed to form the embedded trackbed.

Figure 10: Insulating Surface Barrier at trough edges and polymeric trough components (TCRP, 2002)

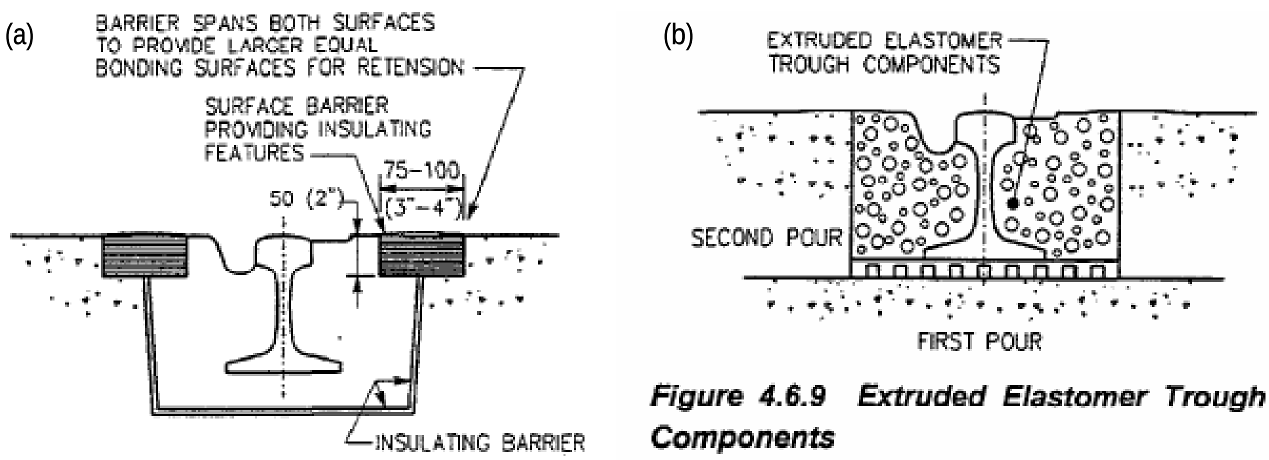
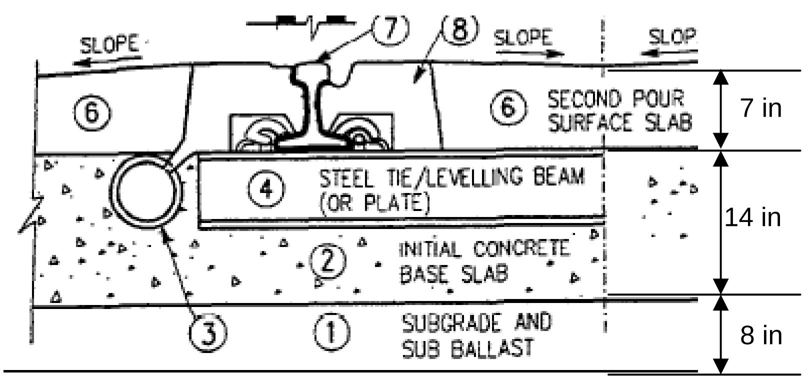


Figure 11: Embedded and Resilient Track Components (TCRP, 2002)



Embedded Rail Components

- Uses a concrete base and no top ballast (1, 2)
- Drainage pipes to the sewer system (3)
- Steel ties or gauge rods are used to maintain gauge between tracks, rather than ties (4)
- Insulating and vibration mitigating materials in the concrete base (6, 7, 8)
- The insulating barrier can be located at the rail boot (7) or around the concrete base (8)

3.2.1.2 Ballast Depth Requirements for Traditional and Modern Track

The average depth of the track bed is considered to be 18 inches for traditional track and 29 inches (2.4 ft) or 0.74 m, for embedded track. However, section 4.1.6 suggests that these numbers could be reduced using minimalist design techniques employed by the City of Portland, Oregon for their streetcar system.

<u>Traditional Track</u>

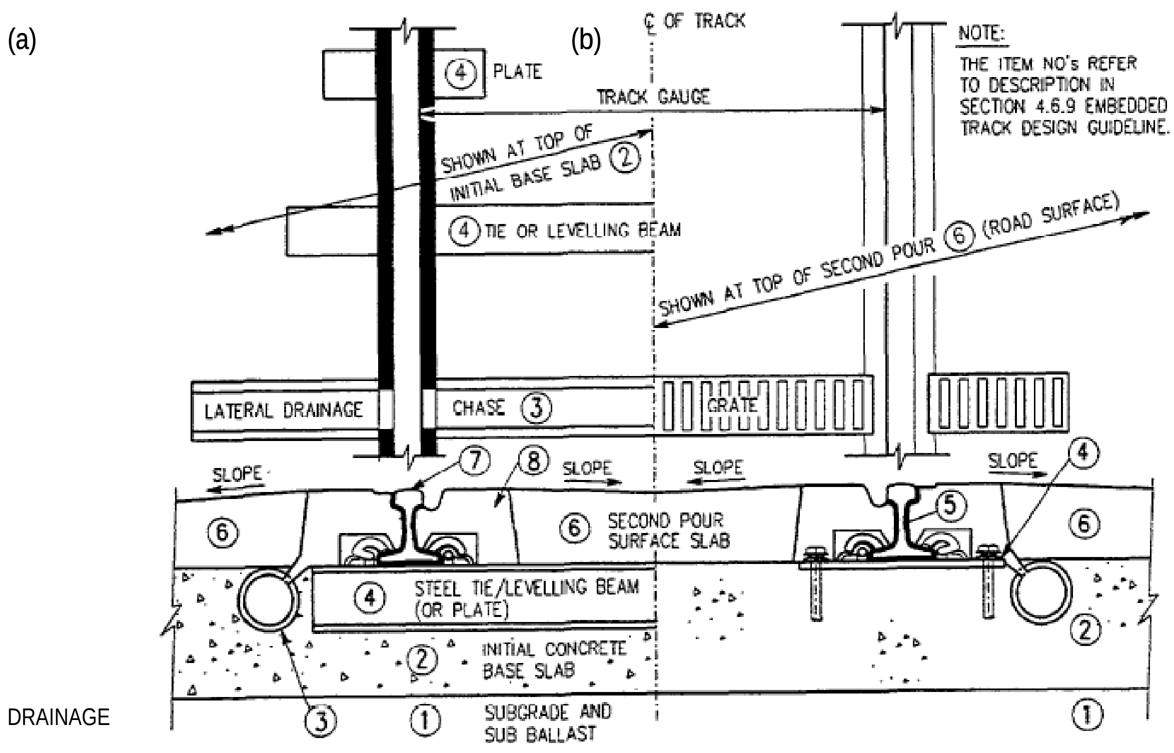
- Used outside of the central business district:
- *Track ballast (10 in depth)* is comprised of crushed stones to form the trackbed upon which railroad ties are laid. It is located under and around the ties and is used for water drainage, load distribution from the railroad ties, and to discourage vegetation growth.
- *Sub-ballast (8 in depth)* is made of small crushed stones. It gives a solid support for the top ballast, and seals out water from the underlying ground.

<u>Embedded Track</u>

- Common in the CBD
- A sub-ballast (8 in) is still required as well as two concrete sections. The section which is laid on top of the sub-ballast (1st Pour) should be 12 to 14 inches. Finally, the surface slab (2nd Pour) should be 7 inches. From the measurements, the total depth of the track is approximately 0.74 m.

A full overview, both topographical and a subsection, of a typical embedded track configuration (a) and a typical direct fixation track (b) is shown in figure 12.

Figure 12: Typical Embedded Track Design (TCRP, 2002)



3.2.2 LRT Stations

A light rail station is a station or stop in a rapid transit system. It can be as simple as a bus stop or as extravagant as an underground or elevated multi-use transit hub. Cities such as Calgary, Alberta and Portland, Oregon, have a variety of stations with interesting architecture or characteristic artistic design that identifies each stop and the community that they serve. It is common to incorporate the work of local artists in the design of major stations. Systems throughout North America have some common characteristics in station design including station spacing, station location and passenger information systems.

3.2.2.1 Station basics

While station architecture varies from city to city, the basic amenities of a station are common to most. Platforms are equipped with shelters, ticket vending machines, ticket validators, posted transit schedules, passenger information screens and station information. Real time "next-train" displays are becoming more common as GPS-based vehicle tracking becomes commonplace in transit networks. Surveillance cameras are also provided to monitor station property for enhanced customer safety. All platforms allow for level boarding to low-floor cars, which have a bridge plate for wheelchairs and strollers to cross the small vertical and horizontal gap at the car threshold, making most stations fully accessible to people with disabilities. Many new low-floor vehicles only require a slight curb to provide level boarding without the use of bridge plates (CMR, 2009).

To accommodate customer access to stations, railway signals, staggered pedestrian barriers and pedestrian gates are used for safety purposes. Large signs posted to warn pedestrians to look both ways for the approaching train, emergency call boxes, automatic audio announcements, bike lockers, covered waiting areas, water fountains, and park and ride facilities (at some stations) provide for additional customer safety and convenience. Park and ride stations are more common on the outskirts of the downtown core so that commuters can park near the station and access the downtown via LRT (CMR, 2009).

3.2.2.2 Station Location and Cost

A review of standard practices in most North American cities indicate that stations are generally located 400 m apart in the central business district, when acting as a local service. In the outlying areas of the city, it is common for stations to be spaced at larger distances apart, between 800 to 1000 m. Most large stations are situated at one end of a city block and are generally as long as the maximum train length that the system accommodates.   Stations can be designed in the median of the street or at the curbside. In terms of cost, stations located at the median have a cost savings considering that there will be half as many stations built along the corridor. This also minimizes station maintenance costs.

3.2.2.3 Station Design Examples

Portland, Oregon has made station appearance and ease of use a priority, reflecting Trimet's goal to create a positive transit experience for passengers. The station architecture is designed to relate to the local community. The Eastside Max Blue Line and Hillsboro stations follow a traditional style, while downtown stations incorporate more contemporary designs.
(Photo Courtesy of Trimet)

Austin, Texas designed each station to incorporate the look and feel of the surrounding community. Capital Metro has built a combination of glass and steel canopies at different stations. They incorporate sun-reflective glass canopies that provide shade, yet permit light to shine through. The glass canopies also feature local artwork.
(Photo courtesy of Capital Metro Transit)
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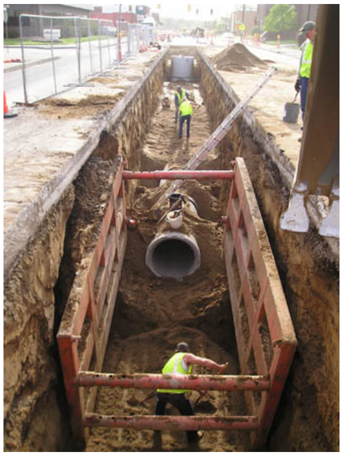
Charlotte (North Carolina) Area Transit system, (CATS) incorporates sustainable cost effective techniques in the design of its stations. Their aim is to promote a livable and sustainable community for both riders and non-riders by committing 1% of design and construction costs for the integration of art into most major projects. This includes stations and their surrounding areas, park and ride lots, transportation centers, maintenance facilities, and passenger amenities.
(Photo courtesy of CATS)

3.2.3 Subsurface Infrastructure



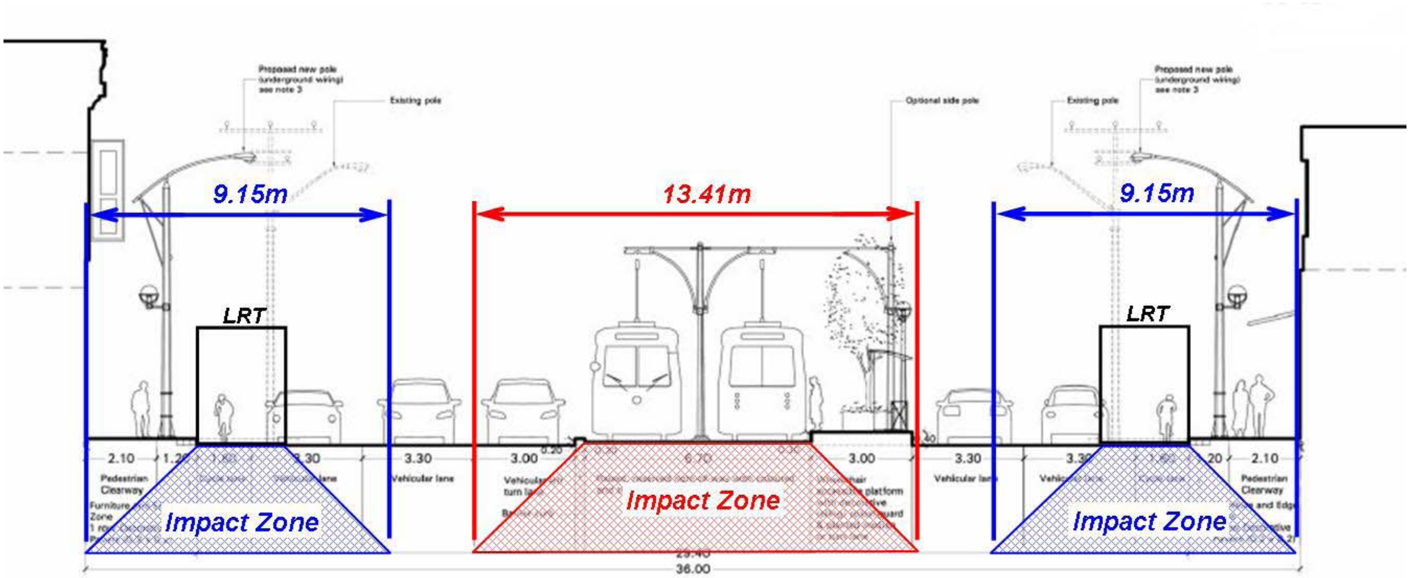
Hamilton's subsurface infrastructure is comprised of all the buried service in the transit corridor. This includes watermains, sewers, gas lines, electrical utilities and communications infrastructure, as well as the track bed which supports the light rail vehicle. In most recent LRT system designs in North America, clearance areas of 5 to 10 feet below and adjacent to the tracks, have been established where no parallel infrastructure should be located. If clearance areas are not established then the LRT service must be interrupted when subsurface infrastructure parallel to the tracks requires servicing.

To avoid disruption, the underground network should be configured so that delays to the LRT system are minimized or eliminated. Any direct physical conflict, such as a manhole in the right-of-way or operational encroachment in the clearance envelope of the LRT should be eliminated. This ensures the safety of road workers and ensures that the LRT corridor is not disrupted by adjacent road work. Subsurface infrastructure must also be moved out of the train clearance envelope to minimize degradation from the light rail vehicle's load and vibration forces and to minimize the possibility of corrosion from stray currents along the LRT track.

3.2.3.1 Utility-free Zone

Transport Canada and other authorities have guidelines regarding the clearance envelope surrounding rail tracks, which defines the utility-free zone where no infrastructure can be installed. Only infrastructure which crosses perpendicular to the track should be maintained in the utility-free zone, provided it is protected from surface loading and stray current. While most utilities parallel to the tracks would have to be abandoned or relocated, many of the sewers which are deep enough to be out of the utility-free zone can be accessed by offset manholes. These manholes do not lie directly over the sewers; rather they are located diagonally sideways from the sewer line. However, it may still be desirable to relocate the sewers entirely (AECOM, 2009).

Figure 13: Impact zones for typical LRT street configurations which outline the utility free zone



The depth of the utility-free zone takes into account the vehicle weight loading on the tracks. In a typical LRT design, the weight of the LRV is concentrated at the track which transmits forces downward and sideways from the point where the wheel makes contact with the track. In the Subsurface Infrastructure (SI) Report (AECOM, 2009), it was determined that for buried flexible and rigid buried pipe the underground clearance (from the surface to the top of pipe) is 11 ft (3.35 m) and 10 ft (3.05 m), respectively. A pipe located within this zone would suffer damage from the train's loading forces over time. Horizontally, pipes within 3 to 5 m of the LRT centreline should be evaluated for risk factors, including possible hazards to the LRT or workers, if the pipe needs to be repaired.

3.2.3.2 Optimal LRT Corridor

Traditionally water pipe and sewer lines are installed in the centre of the road and other utilities to the sides of the road. An LRT system with a median right of way would impact municipal infrastructure to a greater extent than it would impact other utility relocations. In modern street designs, infrastructure is generally built near the curbside rather than the median. In Hamilton's case, building the LRT in the median of Main or King Street in the downtown core, where there are one way streets, could possibly be more expensive, given the age of the road network in the core. However, a median right of way on Main Street West and Queenston Road after the Delta would generally be considered a more feasible configuration.

The SI Impact Assessment (AECOM, 2009) confirms that an LRT configuration which consists of the LRT traveling west along King Street at the curbside and east along Main Street at the curbside, from the Delta to Highway 403, is less expensive to mitigate than an LRT which runs exclusively along King Street in the median from the Delta to Highway 403. An examination of figure 13 visually confirms that the impact zone for a double track along the median is larger, impacting more infrastructure in the CBD.

3.2.3.3 Cost of Infrastructure Impacts

The cost of impacted infrastructure relocation depends on the complexity of the corridor, ease of access to subsurface infrastructure, amount of disruption to transit service that can be tolerated and the inherent safety risks in accessing the infrastructure. SI mitigation is generally 10% to 20% of the total project cost. The costing data contained in the SI Assessment (AECOM, 2009) was based on the following assumptions:

- All sewer and water infrastructure within the LRT right-of-way that parallels the LRT must be relocated because access to maintain the asset will be severely or completely restricted.
- All “branch” sewer mains that currently enter the LRT right-of-way and connect to a “trunk” sewer within the LRT right-of-way must be reconnected when the trunk sewer is relocated. It is assumed that half of those branch sewers will extend through to the other side of the LRT, and that any passing through the structural impact zone will require structural assessment.
- All sewer mains that cross completely through the LRT right-of-way, are below the structural impact zone, and are readily accessible via manholes on both sides of the LRT right-of-way, will remain.
- All sewers that cross completely through the LRT right-of-way as above, but are within the structural impact zone, must undergo structural assessment. Costs to perform these assessments are included in the projection. Costs of pipe replacements required due to insufficient strength are not included in the projection.
- All water mains that cross into or through the LRT right-of-way must be replaced and installed in a casing pipe.
- All sewer and water services entering the LRT right-of-way must be replaced within the right-of-way.
- All water main valve and hydrant relocations are considered inclusive in the costs of main relocation.
- All catch basins within the LRT right-of-way must be relocated (AECOM, 2009).

The City also completed work on the impacts of moving water and wastewater infrastructure on other utilities that are not directly affected, but may need to move when water/wastewater infrastructure is relocated. The utilities are not responsible for paying the full price of relocation. If no agreement between the utility and the city exists then the city and utility share the costs of labour and labour saving devices, 50% each and the utility covers the cost of materials at 100%. Where an agreement exists the breakdown is as follows: gas lines installed after 1981, 35% City, 65% Union Gas; gas lines installed before 1981, 100% Union Gas; municipal water & sewer = 100% of costs to the City.

Based on these assumptions and the data collected by the city, the total cost impact on subsurface infrastructure is estimated to be $70 million for the one-way street configuration in the CBD; and $100 million for the two-way street configuration with LRT only on King Street in the CBD (AECOM, 2009). The full breakdown can be found in the table 2 and includes the costs to relocate utilities that are disrupted as other municipal piping is moved to clear the right of way.

Table 2: Projected Costs to Mitigate the Impact of LRT Development

	Configuration of the CBD (Hwy 403 to Delta)	
Infrastructure Type	1 way on Main St and 1 Way on King Street (Curbside)	2 way on King Street Only (Median)
Municipal Service (water & wastewater)	$50 800 000.00	$73 500 000.00
Utility Relocations	$36 000 000.00	$51 480.00
Utility Relocations (after cost sharing)	$15 300 000.00	$21 879.00
Total (rows 1 & 3)	**$66 100 000.00**	**$95 379 000.00**

3.3 Fixed Equipment

The fixed equipment related to the LRT system includes power supply infrastructure, operations, signals & communication centres and roadside infrastructure (gates, poles, etc). These systems require coordination with power utilities, automated control systems, and communications infrastructure, including the Internet for passenger scheduling communication.

3.3.1 System Power Supply

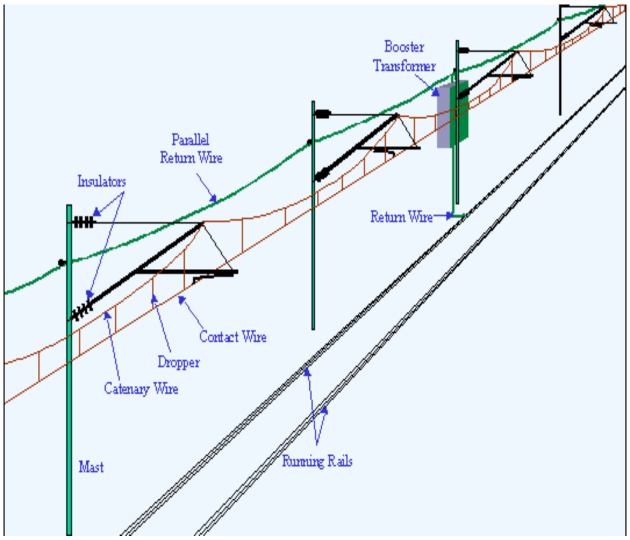
Electric traction systems provide the motive power for LRT vehicles. Over the years, many types of electric traction systems have been developed world-wide. They vary according to type of railway, its location, and the technology available at the time of installation. In recent years, there have been numerous developments in railway traction expansion. This has also coincided with an improvement in power electronics and microprocessors. Fundamental changes in design, operation and manufacture make for highly technical and complex systems (Railway Technical Web Pages, 2008).

Electric traction railways need a safe, economical and efficient power supply that is accessible at all times by the LRV. Trains can use either Direct Current (DC) or Alternating Current (AC). Most systems in North America use DC currents because it is less complicated for railway traction purposes. However, in theory, the more complicated AC systems are more efficient over long distances and less expensive to install.

There are two ways to transmit power along a track; either by overhead wire or at ground level. AC systems can only use overhead wires; DC systems can use overhead wires or a third rail, both being equally common. (Railway Technical Web Pages, 2008).

3.3.1.1 Overhead Catenary Power Supply

Figure 14: Typical Catenary System (Boorse, 1999)



The electric traction system for Hamilton's light rail vehicles could be powered by an overhead, one or two-wire catenary current collector system, using pantographs with the return circuit provided by running rails. Hamilton's system could be similar to Portland, Oregon's where stations are rated for 1MW, connected to an 13.8 kV AC three phase power supply, delivered by the municipal power utility company (Horizon Utilities) at a distance of one 1 to 1.6 km apart. The trains will receive 750 V DC power to drive the traction system and will therefore require AC and DC switchgear, traction power transformers, power rectifiers and programmable logic controllers (PLCs) to automate the process (Boorse, 1999). Transformer substations will be required to convert the 13.8 KV AC municipal supply to 750 V dc power required by the drives, at certain intervals along the corridor. A load flow study is required to determine the actual substation spacing.

3.3.1.2 Load Flow Study

The required power of the system can be determined by measuring the theoretical maximum load on the system for a given headway and anticipated substation spacing. The load flow study takes into account the vehicle's power draw, which for example, can be 0.6 MW when accelerating. Portland, Oregon's study determined that 1 MW substations would be required every mile (1.6 Km). The average catenary height must be determined by additional tests which take into account climatic data, pantograph dimensions and vehicle roll (Portland Design Guidelines, 2002). Hamilton's system could vary in type of substation and the spacing between substations depending on a variety of factors including the projected size and rating of the substations, the timing between trains (headway) and the types of trains used.

3.3.1.3 Catenary Types

The city of Portland required that the visual pollution due to overhead wires be minimized in the central business district. They chose to use a single contact wire rather than the traditional two-wire, simple catenary. The two-wire, simple catenary system consists of a catenary wire, and below that, a contact wire as illustrated in figure 14. The catenary wire supports the contact wire vertically between two structures using hangers and provides more electrical conductivity. There are a few variations of the simple catenary. One is a low profile simple catenary; it has less visual impact because it only requires one cross-span wire for support between poles compared to the two cross-span wires used in the simple catenary system. Structure spacing is reduced to support the lack of cross-span wires and ensure that the wire remains in line with the route at all times. Generally, the dropper cables shown in figure 14, supply power from the catenary to the contact wire and also provide additional support (AREMA, 2008).

In the single contact wire configuration, underground parallel power feeders are used to supply power to the single contact wire at certain points along the corridor, wired through poles. This technique is more expensive, but significantly reduces visual interference. In figure 15, the wires in the image on the right are less visually obtrusive than those on the left.

Figure 15: Simple Catenary vs. Single Contact Wire, significantly reduced visual pollution

(Photos courtesy of the City of Portland)

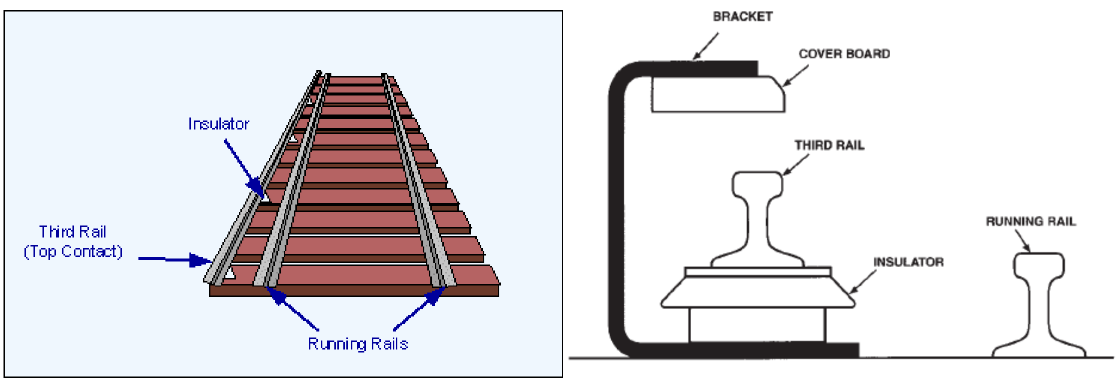
3.3.1.4 Third Rail Power Configurations

In third rail systems, power distribution is provided through an electrified third rail. The energized rail is installed at ground level adjacent to, or in the middle of, the two running rails of each track. It is supported by electrical insulators which elevate it approximately nine centimeters higher than the other track rails. The power is delivered to the train through third-rail “shoes”. These shoes are current collectors that extend horizontally beyond the track frame and slide along the top or bottom of the energized rail (Boorse, 1999).

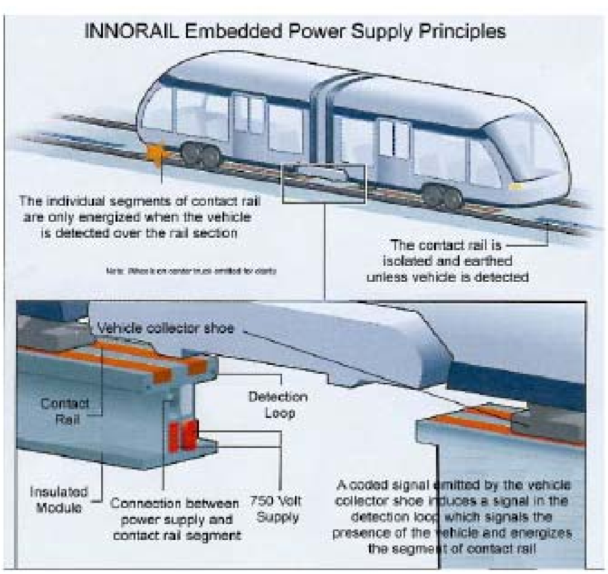
There are considerable safety concerns associated with in-track power systems. At-grade vehicle and pedestrian crossings present a potential risk because of the open electrification. An option exists to create sections of the third rail which are omitted to allow for public street crossings at grade. The gap in the third rail is relatively short, and the train is able to coast across, making these systems viable provided that signage and various safety measures warn pedestrians of the presence of high voltage power lines. However, it is still not advisable to use them at grade because of the obvious safety issues associated with urban applications.

Despite safety concerns, there are several reasons why third rail is suitable in some situations. Third rail is considerably less expensive then overhead wires. On average, the capital cost of a third-rail system is significantly less than for catenary systems of the same voltage. The costs differences branch from how each type of electrical conductor is supported. Figure 9 provides a visual representation of a third rail installation (Boorse, 1999). Depending on where the LRT system is located, such as corridors with limited pedestrian or other interactivity, traditional third rail may be a viable option. However, for Hamilton's proposed on-street system, it is not preferred.

Figure 16: Typical Third Rail Configuration and installation (Boorse, 1999).

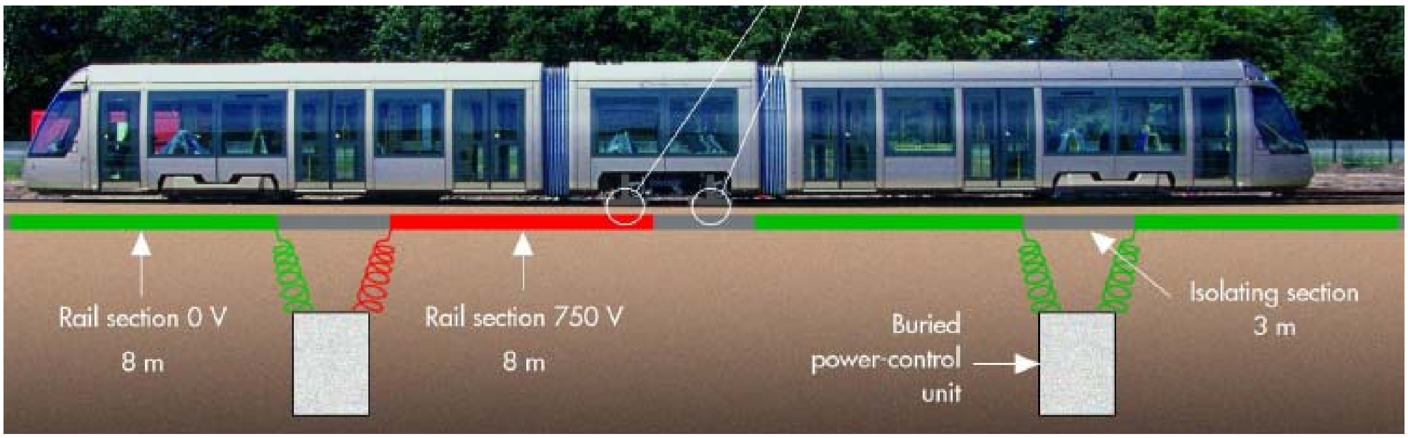


3.3.1.5 Embedded Power Supply - APS



The best example of a light rail system using third rail that has overcome the dangers associated with open electrification is in Bordeaux, France. Originally, the system was designed devoid of wires for aesthetic reasons in an architecturally important and sensitive area of the city adjacent to a Cathedral. The system chosen was designed by Spie Rail, and known as INNORAIL; later purchased by Alstom and marketed under the name APS. The portion of the system using APS technology is approximately 10.5 Km in length. It contains the typical elements of a third rail system but also includes a series of switched contact rails installed between the running rails. The switched contact rails are separated by insulated rail sections to ensure complete electrical isolation of each section. The only time each individual section is energized is when its local power rail contactor receives and verifies a low power, specially coded signal, which comes from a transponder in the approaching rail vehicle. The signal can only be detected when the vehicle is directly over the switched contact rail. At all other times, the power rail segment is automatically grounded, which means no power flows through it. Also, there are two sets of shoes on the vehicle to ensure a continuity of power as the vehicle crosses the insulated sections (Swanson, 2003). In figure 17, only the red section is powered, as the transponder and contact shoe come in contact with the rail section.

Figure 17: Alstom's APS System allows the design of a safe street level third rail system (Alstom, 2008)



According to Alstom it is possible to adapt APS to North American systems when cost, safety and engineering are considered. However, major considerations for ice and snow in the Canadian climate have to be made.

3.3.1.6 Using Both Overhead and Third Rail – Dual Mode Power Distribution and Collection Technology (DMCC)

As an alternative to using either catenary or third rail technologies, it is possible to use a combination of both. For a Dual Mode Power Distribution and Collection Technology system to work, the trains would have to have both third-rail shoes and pantographs installed. The physical and operational requirements are significantly more complex than just using one system or the other. The most critical of these requirements is the equipment necessary to make the transition from one collection mode to the other. This transition would have to be seamless, and would have to be accomplished without the installation of unattractive or extremely costly equipment (Boorse, 1999).

Design components include a section of track at the transition point between catenary and third rail where the two distribution types are overlapped. This section would have to be lengthy enough to accomplish the change without delaying the trains. Therefore, the length required is a function of this transition occurring at full operating speed and would have to be determined by conceptual models or test runs to ensure optimum performance (Boorse, 1999).

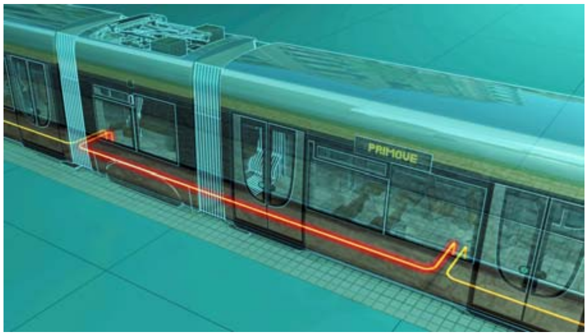
The process whereby the two distribution points switch is relatively simple. As the train operating under the catenary wire system approaches the entrance to the third rail system, the third rail shoes are deployed. Upon contact with energized rail, the on board switching mechanism would disconnect traction motors and other electrical equipment from the pantographs and connect to the third rail shoes. The pantograph would then be lowered and the train would continue on the third rail electrical distribution system. In the reverse direction, the third rail enters an overlapped section where a contact wire is present overhead. The pantographs would rise, and once in contact with the overhead wire all electrical equipment would be disconnected from the third rail shoes, and the shoes would retract. The shoes would have to retract to a certain point underneath the train, especially in a street environment, so they are not broken or damaged by street debris (Boorse, 1999).

The ability to use both catenary and third rail would be particularly beneficial to the City of Hamilton because of some under-bridge crossings in which the bridge height is not high enough to support the overhead catenary system. For example, the Hunter Street Bridge (A-Line) is quite low and will need special consideration (see section 4.1.3). The combination of both third rail and catenary systems could be the best solution to this problem.

3.3.1.7 Experimental Power Systems – PRIMOVE Induction Power System

PRIMOVE is an alternative to catenaries that powers trains using an embedded third rail know as an induction power system. This scheme uses induction power, which incorporates electromagnets to achieve a contactless power transfer as the train's current collector passes over a buried wire. The system, developed by Bombardier, can accommodate all weather conditions since it has no physical contacts. PRIMOVE is currently in the testing phase and has not yet been incorporated in a commercial vehicle.

This system is similar to APS; however, the third rail is buried underground and the contact between the train and the rail is air, rather than metal. These underground wires carry current from the supply network to power the train (Figure 18). As the train's pick up coils pass over the supply wire, an inductive current is created only where the train is located, without physical contact. The other sections of the track not under the train are electrically isolated, as they are in APS (Figure 19). A major difference between PRIMOVE and APS is that PRIMOVE does not require the use of running rails as a return circuit. This could significantly reduce issues associated with stray current and erosion (Bombardier, 2008).



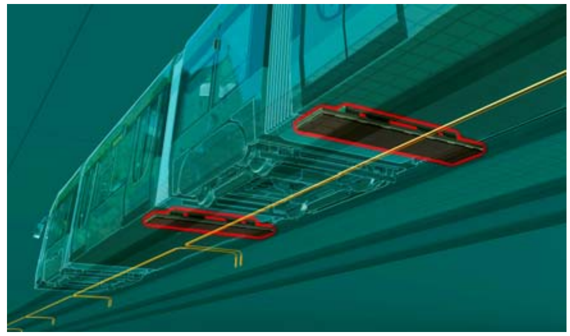


Figure 18: Underground Inductive Power

Figure 19: Train Cab Power Pick-up Coils

(Photos courtesy of Bombardier Transportation)

3.3.1.8 Power Systems Comparison

Overhead catenaries require a series of moderately elaborate structures to support them. At a minimum, these structures are composed of a concrete foundation, a steel column and a lateral arm. The distances between support points can be as great as 80 m, providing that the track alignment is flat and straight. However, any significant vertical or horizontal curvature in the alignment necessitates a closer spacing of support structures and greater expenditure to keep the wires properly positioned over the track. Also, for shorter radius horizontal curves it is often necessary to provide “pull offs”. Pull-offs are cables that provide no vertical support, but are required to pull the catenary outward horizontally to keep it positioned over the track. These require additional poles to be constructed at points between the main support structures.

Third rail electrification requires no complex structures. The conductor rails are simply attached to the ties or slabs that support the running rails. A simple metal bracket that sustains the electrical insulator where the third rail is placed acts as the hardware. The third rail itself is easily adaptable to vertical and horizontal changes in the track. The distance between support points does not need to be reduced when there are significant changes in the track surface, as is necessary with overhead wire, because the running rails are rigid. Maintenance costs also differ significantly between in-track electrification systems and over head electrification systems. When catenary systems are designed to have fixed anchors, they require additional seasonal attention that is not required for systems with fixed tension. In more severe climates, these additional seasonal maintenance requirements are often more pronounced (Boorse, 1999).

Both systems are vulnerable to severe weather. Overhead wires are subject to winds, tree branches, and extreme temperatures. Third rail is vulnerable to deep, wet snow. However, Bombardier’s PRIMOVE may be able to avoid this issue, as the supply wire is buried in the ground. For regions such as Hamilton with severe winter weather conditions, it is difficult to account for all factors that may affect the reliability of either medium. In more moderated climates, however, third rail is generally considered less problematic then overhead wire (Boorse, 1999).

In terms of capital costs, while traditional third rail is less expensive than catenary systems, embedded third rail installations can be more costly. The city of Bordeaux only used APS in its CBD because of its high installation cost. Bombardier's PRIMOVE is not yet on the market, so its capital costs are unknown.

3.3.1.9 Fossil Fuel Equivalent Energy Use

Determining the efficiency of LRT, personal vehicle use, bus rapid transit (BRT) and other forms of transit, has been cause for much debate. It is generally agreed upon that LRT, when electricity is used as the main power supply, is more energy efficient than BRT and personal vehicle use. A study published by Puchalsky in 2005 compared BRT and LRT directly to determine which of the two had lower emissions and energy consumption overall. Puchalsky compared the best scenario LRT system and BRT system as well as the average LRT system and BRT system efficiencies. United States averages for electricity consumption per passenger mile were used.

Electric rail vehicles emit no propulsion system pollution at their point of operation. The only point of pollution for LRT systems is at the power plant from which the system gets its electricity. BRT systems, however, pollute at their point of operation, causing decreased air quality in core areas and along corridors where the buses are in operation (Puchalsky, 2005). LRT systems are responsible only for fuel cycle emissions from electricity generating plants; these are not necessarily operated in the city, as with Hamilton, reducing on-site pollution effects. Fuel cycle emissions refer to a complete accounting of emissions and energy use from primary feedstock extraction through final energy use. Overall, Puchalsky (2005) found that LRT systems create less pollutants then BRT systems.

A study completed by Light Rail Now, a support enterprise for developers of LRT, in 2007, also found similar results when comparing LRT to other forms of transit and personal vehicle use. The following chart represents their findings when comparing Urban Transportation Energy Intensities.

Figure 20: Urban Transportation Energy Intensity - Major Modes (BTUs per passenger-Mile)
(Adapted from Light Rail Now, 2007)

Transportation Mode	BTU/passenger-mile
Commuter Rail	2, 743
Light Rail Transit	3, 473
Trolley Bus	4, 004
Motorbus	5, 410
Automobile	5, 760

It is possible for light rail systems to have a 'zero' emissions system. This occurs when the energy being produced for the grid comes from a sustainable source, i.e. wind, solar or water. The ratios of fuel sources for electric power generation can also be modified to make the light rail system more efficient. For example, Calgary, Alberta has subsidized its power generation with enough renewable energy from wind power to make the system have a net carbon footprint of zero. In Ontario, the fuel sources for electric power generation are changing. By 2025, the goal is to have a higher percentage of fuel sources be renewable (Ontario Ministry of Energy and Infrastructure, 2008). There will be an increased reliance on nuclear energy and other renewables (wind, water and solar). This means that the overall efficiency of LRT systems will increase because the sustainability of the power supply has increased.

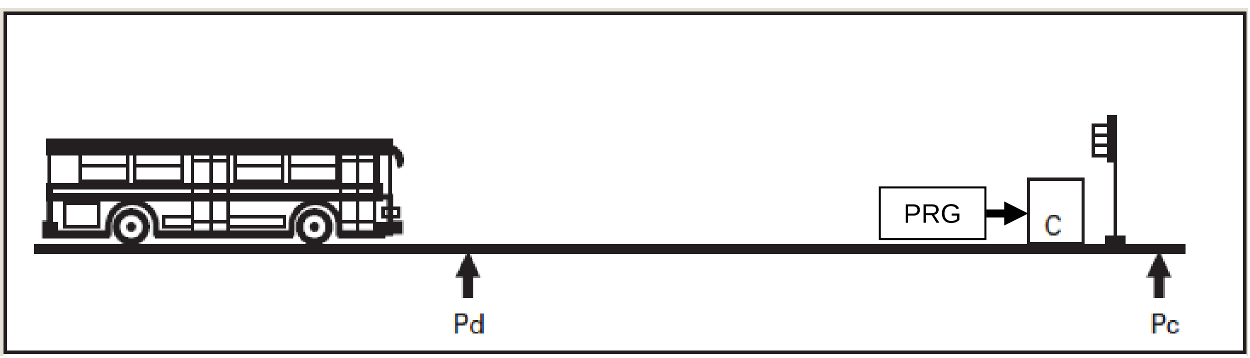
3.3.2 Intelligent Systems

Intelligent systems serve various functions. They increase the efficiency of the system, make the system more user-friendly, reduce congestion at intersections, increase the speed of the system and improve customer service.

3.3.2.1 Transit Signal Priority (TSP) / Pre-emption

TSP is vital to ensuring that traffic lights allow the train to pass through without stopping, when it is detected to be in proximity to the traffic light, as shown in figure 21. This improves schedule adherence, increases transit travel time efficiency and minimizes impacts to normal traffic operation.

Figure 21: Basic Operation of a Transit Signal Priority System (Smith & Hemily, 2005).



- Pd (check in point) – detects the transit vehicle and signals the priority request generator (PRG) that a request for priority has been made.
- The system interprets the PRG signal and determines whether the traffic signal controller (C) should be truncated (if red) or extended (if green)
- Pc (check out point) – transit vehicle has passed through the intersection and C releases priority and recovers so that the traffic light re-synchronizes to the network.

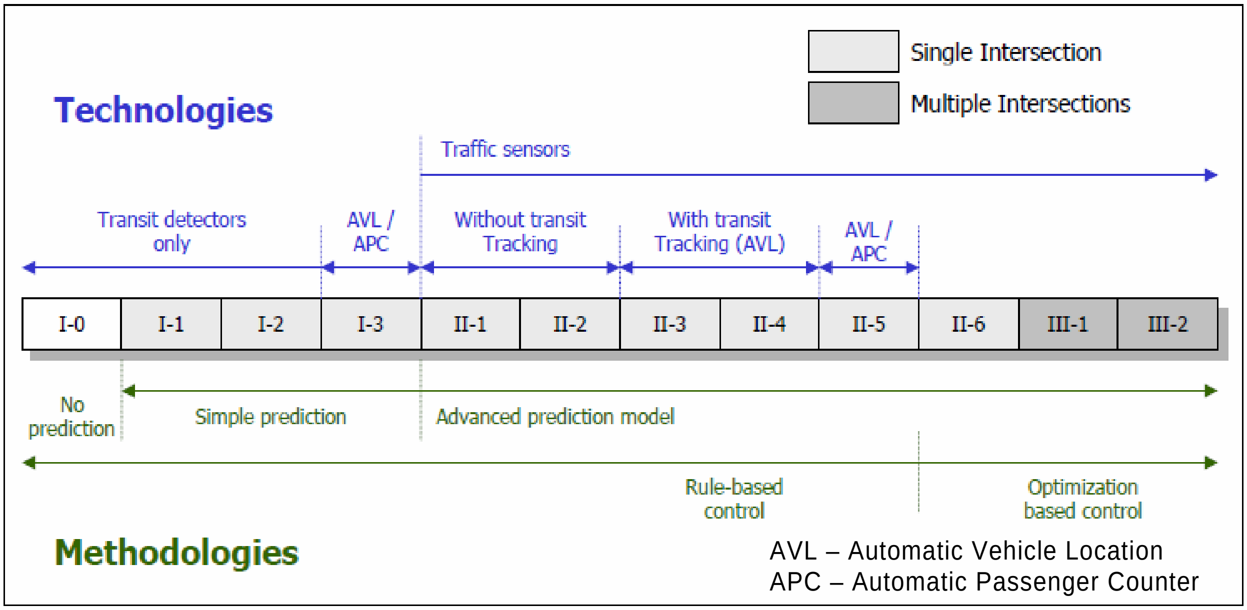
The priority control provided by C can use a variety of strategies or algorithms as outlined in table 3. Each of these has certain benefits and drawbacks.

Table 3: Benefits and Drawbacks of Various TSP Strategies (Hung, et. al, 2005)

Type	Function	Issues/Benefits
Passive Priority	Signals are timed to match transit patterns	• Allows the use of existing signals
Unconditional Priority	Priority given to every transit vehicle every time a signal is pre-empted	• Vehicles may run ahead of schedule increasing traffic congestion • Cost Effective since it does not require complicated algorithms or electronics
Conditional Priority	Evaluates the benefit of providing priority, based on certain conditions, before priority is granted	• Can use passenger counts and vehicle locations • Central systems can monitor traffic at an intersection
Adaptive Priority (Predictive modelling)	Evaluates priority based on real time traffic data and can handle requests several timing cycles in advance	• Can adjust signal timing plans at the intersection in advance therefore eliminating any delay caused to other traffic

The technologies used to achieve transit signal priority can be organized in a hierarchy (figure 22) from the simplest to the most complex. Referring to figure 22, scheme I-0 to I-2 use passive and unconditional priority; scheme I-3 uses conditional priority and schemes II-1 to III-2 use adaptive priority in a variety of configurations. Hamilton's LRT and street light system will require one of these schemes, which can be chosen based on the system requirements and available funding. The expense of the system increases up the hierarchy, so cost will be a factor and needs to be measured against the potential benefits.

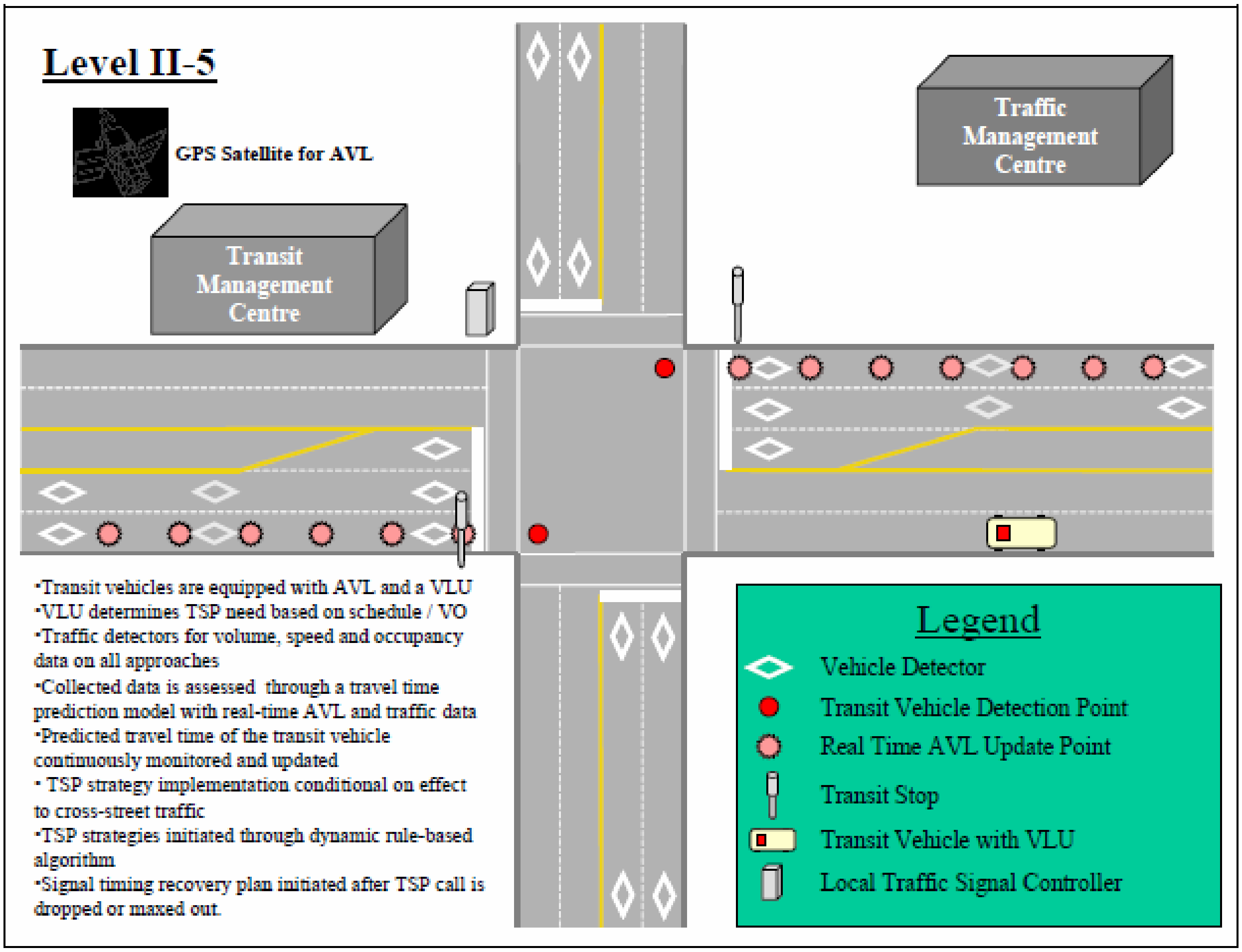
Figure 22: Transit Signal Priority Technology Hierarchy (Hung, et. al, 2005)



3.3.2.2 Transit Signal Priority Example

Figure 23 is an example of an advanced transit signal priority system. This system uses adaptive priority from a central operations centre. In figure 21, C, the controller, performed the analysis locally. In this example, the analysis of system state is done centrally so that information from other controllers and street sensors can be compiled and analysed. The vehicle detector diamonds, embedded in the roadway, monitor traffic in real time and supply this information to the central controller. The automatic vehicle locator (AVL) uses GPS transponders to accurately monitor the vehicle's location at or near the intersection. This data, along with data from other parts of the corridor, allow the system to predict whether priority will need to be granted and if so, its effect on the system. This type of logic increases the efficiency of the system, allows the intersection to recover from the change better and minimizes the effects to traffic at the intersection (Hung, et. al, 2005).

Figure 23: Advanced Transit Signal Priority Example (Hung, et. al, 2005)



3.3.2.3 Transit Signal Priority Benefits Example

The city of Brampton tested different types of TSP algorithms to examine their effect on delays to transit vehicles and delays to side street vehicles at intersections. Active TSP improved bus delays but had little or negative effects on side street traffic. When Adaptive TSP with prediction was tested, the bus delay and side street delay was minimized. The following table summarizes these results:

Table 4: Results of Different TSP Algorithms in Practice (Hung, et. al, 2005)

Type	Bus Signal Delay (sec/interval)	Side Street Delay (sec/vehicle)
None	36	34
Active	28	39
Adaptive	18	35

3.3.2.4 Transit Information Systems

Using the global positioning system (GPS) and sensors, the positions and schedule of the train are monitored and displayed using LCD panels in the trains and at stations.

This type of system is a standard feature in most new transit systems. Depending on the type of sensors used, world wide web interfaces can provide accurate, real time locations of transit vehicles along their routes.

These systems improve the customer experience and allow system users to better plan their routes and schedules. The ability for passengers to obtain updates via their mobile phones is vital to providing an efficient level of service in the future.

4. Technological Challenges and Mitigation Strategies

The proposed A-Line and B-Line corridors encounter some complicated geographical and engineering challenges due to the city's existing infrastructure and extensive grade changes. Particular challenges include: the escarpment crossing, Highway 403 Interchanges in the City's west end, which may require a flyover; the roadway under the TH&B bridge (at Hunter Street) and the pedestrian walkway over King Street, which may need to be lowered to accommodate the train's catenary system; property acquisition for station locations; limited right-of-way in certain parts of the corridor; climbing the escarpment and issues with corrosion and vibration.

Overcoming these challenges will include research into vehicle types and public works projects. The measurements of some vehicles make them more ideal for the under-bridge crossings, requiring only minimal road lowering. Catenary-free vehicle technologies can also help solve the problem of bridge crossings while minimizing visual impacts and maintenance costs. In terms of corrosion and vibration control, various resilient technologies and materials exist to soften metal-on-metal forces, isolate running rails from surrounding infrastructure and extend the life of rails and wheels in the process.

4.1 Standard Gauge vs. TTC Gauge

Rail gauge is a measure of the distance between two parallel rails. The standard rail gauge used throughout North America is 4.7 feet (1.435 m), which is slightly narrower than the 4.9 foot (1.495 m) gauge used by the Toronto Transit Commission. The TTC is unique in North America and Europe, as they are the only transit system to use this non-standard gauge. The historical reasons for this include: acting as a barrier to freight train traffic in the downtown core (as was popular in other cities) and to allow vehicles with narrower gauges (such as wagons) to be pulled inside the tracks.

In terms of combined procurement strategies, Metrolinx and Hamilton may have to decide between using the TTC gauge and using the standard gauge, depending on the advantages of either strategy. According to Mario Peloquin of Siemens (personal communication, Dec. 18, 2008), use of standard gauge vehicles would make the system compatible with all other North American systems. In addition, the replacement cost of a standard gauge vehicle would be lower than that of a TTC gauge because the TTC-style train requires a full redesign of a standard vehicle bogie and would prohibit Hamilton from using models of other companies in the future. However, it is possible that a TTC gauge vehicle order of a certain size could help make the case for building the LRVs in the Greater Toronto and Hamilton Area rather than elsewhere.

Table 5: Standard Gauge vs. TTC Gauge Comparison Summary

Standard Gauge	TTC Gauge
1.435 m (4.7 feet)	1.495 m (4.9 feet)
Used throughout North America	Used only in Toronto
Is generally the standard in European LRT systems	Historically used to discourage freight traffic in the downtown
Benefits Hamilton: • Lower vehicle replacement cost • Compatibility with other train systems for future expansion • Avoid costly redesign of the bogies • Siemens, Bombardier and Alstom recommend standard gauge	Benefits to Hamilton: • Lower capital costs when combined with TTC order • Encourages local (GTA) manufacture of the trains

4.2 Grade Differences

While Hamiltonians may affectionately and inaccurately call their piece of the Niagara Escarpment a mountain, the task of climbing it presents a mountainous challenge. While, not an impossible task, no known light rail vehicle in North America can climb a grade of greater than 9%. Most manufacturers agree that a maximum 9% grade can be climbed for more than 1 Km with fully motorized bogies. The grade of James Mountain Road is nearly 2% steeper (10.8 %) than this maximum.

Climbing a grade depends on several factors including the type/model of vehicle, the length of the grade and the weather conditions that will be encountered throughout seasonal changes. For instance as the weight of the train increases, its ability to climb a grade decreases. In San Francisco, a city known for its steep grades, the streetcars used to climb the hills of the city employ a latching mechanism which grabs on to a rope that is driven by a motorized pulley system in between the tracks. This type of system would not operate well in cold and snowy winter conditions and it would not be compatible with LRT technology (personal communication, Mario Peloquin, Dec. 18, 2008).

Other grade climbing options presented to date are listed in table 6.

Table 6: Summary of Grade Climbing Options Investigated

Option	Issue
Escarpment Tunnel	• Costly and unpopular with the public • Disrupts the natural environment
Claremont Access	• Increases the length of the route, making it inefficient (additional 6 minutes in travel time) • Does not service all nodes
James Mountain Road	• Has an 11% grade which cannot be flattened/stretched • Trains can only achieve a climb of 9% at maximum (depends on vehicle size and length of grade)

Mitigation Strategy: In some mountainous European communities, railway cars usually travel up hills using rack or cog railways. These rails include a third, toothed rack rail (a cog rack) in the middle of the tracks, to which the train's spur gears are used to latch the cogs (or pinions) on to, in order to drive the train up the grade (see the figure below)

While generally used as independent rail systems to move passengers up mountains, in at least one example, cog railways have been used in modern transit systems. Line C of the Lyon Metro, in France, is an example of a system that employs cog rail in steep sections of the track which lies at a 17% grade at its steepest. The trains, Alstom Vevey (MCL 80), were designed by Alstom in 1984, and are capable of running on both rack sections and non-rack sections of the track.

4.3 Bridge Underpass

In two locations along the A-Line and B-Line, bridge crossings could present a problem with train crossings below them. According to the Rapid Transit Feasibility Study Phase II (2008), the minimum clearance required for LRV cab, pantograph and catenary wires is 4.6 to 4.8 m. This is true for older Siemens train models; however newer low floor models from all three manufacturers hold promise for being able to pass under the bridges without significant road lowering requirements. The height of the TH&B bridge is 3.9 m and the height of the Summers Lane Pedestrian Bridge is 4.2 m.

Mitigation Strategy: A variety of options exist to mitigate this issue

- Lower the road under the bridges
- Evaluate the Siemens Combino Plus and Bombardier Flexity Outlook low floor LRVs
  - The low profile of the vehicle can clear the 3.9 m height of the bridge (according to Siemens)
  - Min. Pantograph Operating Height: 3.9 m (from top of rail)
  - Min. Catenary Wire Assembly Area: 0.2 m
  - Only minor road lowering will be necessary for the TH&B bridge
  - Using PRIMOVE or APS could eliminate the need for overhead wires

4.4 Vibration/Noise Mitigation

There are some concerns that medical applications near hospitals could be affected by train vibrations. In the experience of Houston, Texas, the Siemens S70 travels past 7 hospitals, some near the curb side with no known issues. However there are a variety of strategies that can be employed to mitigate vibration and noise concerns.

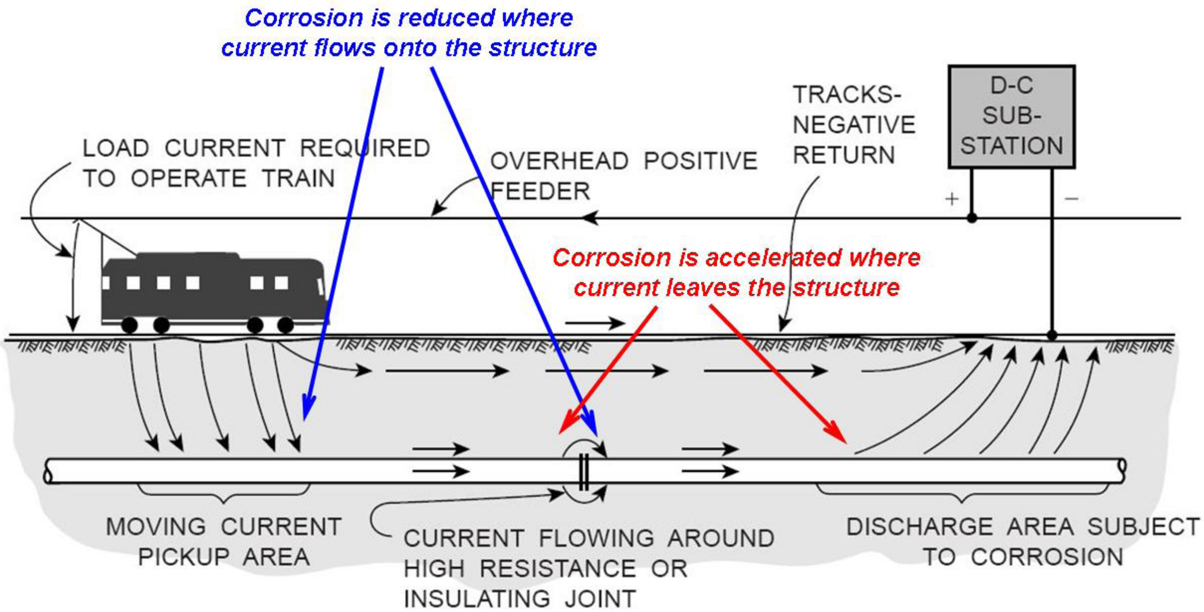
Mitigation Strategies:

- Increase the resiliency of the track and track bed
- Use "soft wheels" which are rubber pieces added to the wheel shell
- Rubber Rail Boots can be used to encase the rails and absorb vibration
- Vibration Mats/Concrete Slabs can be installed the under the track ballast
- Minimize curves, crossovers, and turnouts in the track work help eliminate noise from sharp turns
- Use automated rail lubricators which periodically release lubricants on sensitive areas of the track
- Construct Noise Barriers and Sound Absorbers in sensitive areas

4.5 Stray Current and Corrosion Control

Electrolytic corrosion can occur in underground infrastructure due to leakage (stray) currents from the track rails, especially with DC power systems. The running track provides a path for electricity to flow from the catenary wires; however, electricity can stray from the rails and flow to other infrastructure. Leakage currents can cause and accelerate corrosion in underground piping, steel reinforcement in concrete structures and may damage underground utilities (AECOM, 2009). Figure 24 shows the effects of stray current when electrical insulators fail to protect the surround region and allow current to escape the running rails.

Figure 24: LRT Stray Current Activity on Buried Utility (AECOM, 2009)



Mitigation Strategy: There are a variety of measures to limit the effects of stray current

- Cathodic Protection of piping with the use of galvanic anodes to attract electric currents away from the piping, by becoming sacrificial electricity attractors.
- Electrical insulation of underground piping and utilities
- Electrical isolation of embedded track from the earth with plastic/concrete encasement
- The use of continuous welded rail, so as to minimize joints which could cause current to stray
- Insulating either individual rails or the entire track structure from the earth.
- Continuous welding of the steel reinforcement in the supporting base slab to act as a stray current collector and electrical drains to carry intercepted current back to the traction power substation (Portland Design Guidelines, 2005)

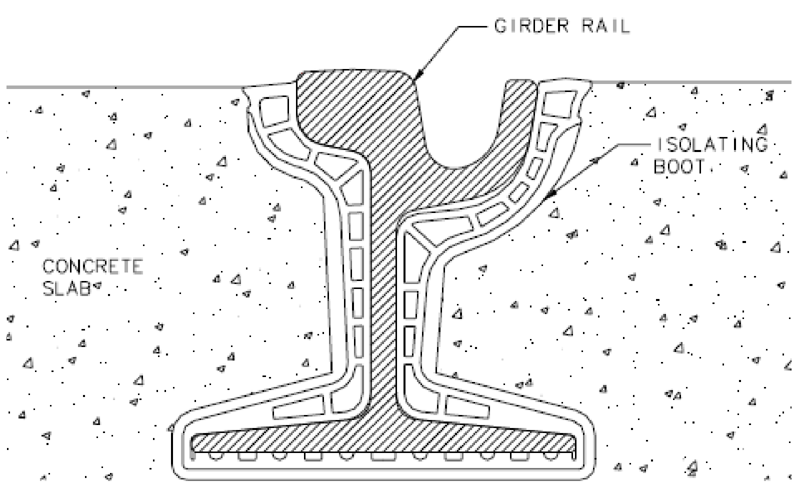


Figure 25: Example of a steel rail isolating boot

4.6 Clearance Requirements

In order to provide un-interrupted LRT service and preserve the track bed, it is recommended that no parallel infrastructure lay under the track. An additional horizontal clearance of 5 feet on either side of the track is also recommended for safe access to the infrastructure. For piping and wiring that crosses the track perpendicularly, a clearance of 10 feet (3m) below the track is required due to the weight of the vehicle and the track base.

Mitigation Strategy: While this is a key challenge, researching the alternatives to traditional track bed design and the use of traditional light rail vehicles may help mitigate some of the issues. This would include using a lighter vehicle in order to lessen the 3 m, worst case, under-track burial requirement. It may also lessen the need to move some infrastructure.

The design of the Portland, Oregon streetcar uses lighter and smaller Skoda-Inekon T10 trams that exert less force on the subsurface infrastructure. They also use a shallow slab construction technique that minimizes the amount of subsurface infrastructure that needs to be relocated. The track depth is only 12 inches, mainly because the trams are only 2.46 m wide and 20 m long. These measurements limit the need for large horizontal clearances of infrastructure and roadway. A minimalist design such as this one also brings down the capital costs of construction. According to the city of Portland, building the streetcar system cost $14 million/Km, in 2001 US dollars (Light Rail Now, 2005b).

Hamilton could further explore the Portland Streetcar system to evaluate its applicability to Hamilton's light rail transit plans and challenges. See Appendix B for a comparison of Hamilton's proposed train, the TTC's CLRV Streetcar and the Portland Streetcar.

4.7 Relocation and Cost of Existing Subsurface Infrastructure

Relocating and replacing existing infrastructure is time consuming and costly; however, it provides an opportunity for infrastructure renewal and reorganization. In Hamilton, the costs would be shared with the local utility providers as such:

- Municipal water & sewer = 100% of costs to the City
- Gas (lines after 1981) = 35% city, 65% gas utility; (lines before 1981) = 100% gas utility's cost
- Electricity = 50% City, 50% Horizon (includes cost of labour and labour saving devices, not materials)
- Bell and other telecommunications = City in process of developing agreements for 100% cost to the utility (with Bell services, anything before the agreement is 50/50)

Where no agreement exists, according to Ontario law, the costs with the utility must be shared 50/50 on labour and labour-saving devices but the cost of materials is paid for entirely by the utility.

Mitigation Strategy:

- Identify and confirm the location of existing subsurface infrastructure to determine impacts
- Identify the condition of existing infrastructure to determine the replacement need and risk of not relocating it
- Select the optimal transit corridor location. This is typically the median of the road way because most new infrastructure is located at the curbside.
- An LRT system running in the median of the roadway would avoid the need to relocate some infrastructure; however, this depends on the amount of space the LRT system occupies in the median (see section 3.2.3.2 and 3.2.3.3 for further analysis).

5. Operating and Maintenance Financial Considerations

5.1 What are Operating and Maintenance Costs?

Modern light rail transit (LRT) vehicles, like all mechanized devices, have costs associated with their operation. These costs include the maintenance of the vehicle, tracks, stations and power infrastructure. They also include the costs to operate the vehicle, such as driver salaries and electric power supply. Many of these costs are similar to those incurred by other transit vehicles such as busses and heavy trains. Proper operating and maintenance is vital to ensuring a high level of reliability and to maximizing the operating life expectancy of the system. It also helps protect the city's investment by maintaining a positive image and high level of service.

5.2 Costing Issues

The majority of the capital costs for the proposed Hamilton Rapid Transit project will be funded by the province of Ontario's MoveOntario 2020 plan, administered by Metrolinx through the Regional Transportation Plan. Therefore, it is important to project realistic operating and maintenance costs for the system, since it represents the greatest on-going cost to the city. Some transit literature and research indicates that LRT systems are less expensive to operate then bus-based systems. Others have concluded that the opposite is true. It is important to be cautious as to how this comparison is made and what is being compared. For instance, basing the comparison on a per-vehicle factor, may bias the results because each LRT holds as many passengers as 2 - 4 busses (depending on the length of the train). Furthermore, one must ensure that the comparison is fair. As an example, if station maintenance is included in the LRT costs then it should also be included in the cost of BRT systems.

5.3 Examining Transit Data

One way to estimate operating and maintenance costs is to examine the data from other cities which operate both LRT and BRT. The United States National Transit Database (NTD) collects the capital, operating and maintenance costs for all transit operators in the country. Data for Portland, Oregon, Minneapolis, Minnesota, and other major North American cities which operate multiple modes of transit were analyzed (see table 7). The results were compiled as direct costs, cost per passenger mile traveled (PMT) and costs per unlinked passenger trip (UPT). Passenger Miles Traveled (PMT) is the cumulative sum of the distances traveled by each passenger; Unlinked Passenger Trips (UPT) is the total number of passengers who board transit vehicles per mode. These measures allow a fair comparison to be made between different transit modes by making the data relative to the usage rate of each system.

5.4 Results

Table 7 illustrates that on average, the operating and maintenance costs for LRT systems throughout North America are significantly less than the costs to operate bus systems. The savings are as high as 60% (Houston, Texas); however, in some cases, bus costs were less than LRT costs (Pittsburgh). Results were not always similar between the PMT and UPT measures. For instance, in Pittsburgh, there was savings per passenger mile, but extra costs when the data was analyzed per unlinked passenger trip. In Pittsburgh, the low population may also have an effect, given the data, which indicates that populations of less than 300,000 may not efficiently support an LRT system due to low ridership.

Table 7: Operating and Maintenance Costs for Selected North American Cities by Passenger Miles Traveled and Unlinked Passenger Trips

City, State	Population	Per PMT		%Diff *	Per UPT		%Diff *
		BRT	LRT		BRT	LRT	
Denver, CO	588,349	$0.67	$0.34	**-49%**	$3.60	$2.17	**-40%**
Houston, TX	2,208,180	$0.55	$0.53	**-4%**	$3.18	$1.29	**-59%**
Minneapolis, MN	377,392	$0.72	$0.42	**-42%**	$3.20	$2.41	**-25%**
Pittsburgh, PA	311,218	$0.90	$1.23	**-37%**	$4.29	$6.00	40%
Portland, OR	550,396	$0.93	$0.39	**-58%**	$3.27	$2.04	**-38%**
San Diego, CA	1,266,731	$0.71	$0.27	**-62%**	$2.62	$1.59	**-39%**

*The % Difference indicates the difference between the LRT and BRT values. If the LRT value is less than the BRT value, then a negative percentage is shown.

Hamilton's population is similar to that of Portland's and Denver's, and therefore would be well suited for BRT or LRT. Also, many of the cities which demonstrated low LRT operating costs have complimentary planning policies that support transit oriented development. When comparing the operating costs for bus and LRT in the same corridor, it is clear that based on the NTD data, an LRT system could have reduced costs and lessened burden on taxes than a bus service. However, upon further analysis there may be reasons for this trend that clarify the outcomes, as demonstrated below.

5.5 Analysis

The evidence presented is inconclusive because the bus system, by its very nature, operates in corridors of low ridership to feed the major transit trunk lines. Bus Rapid Transit (BRT) and LRT systems are usually placed in areas with the highest potential for ridership. Since ridership is the variable which effects the cost per rider trip measure, costs measured per trip would favor LRT and BRT trunk lines. A better comparison would be to evaluate BRT and LRT in the same corridor. This cannot be done in practice, because a trunk line usually contains one mode or the other. However, one can do this theoretically by varying parameters and mathematically modeling a sample transit system.

Eric Bruun (2005) performed one such study published in the Transportation Research Record in 2005. His study estimated operating cost differences for BRT and LRT using a parametric cost model and National Transit Database (NTD) information. The study assumed train sizes of 28 m and bus sizes of 18 m. Marginal cost estimates were included to more accurately describe peak hour demand costs, when additional vehicles are required to meet demand. The study was completed for a medium sized city, based on Dallas Texas and using the data from all cities reporting in the NTD. It was also assumed that the cost to operate one light rail vehicle (LRV) per year is $1.4 million; the cost for one bus per year is $600 000; and the cost for one BRT is between $835,000 to $934,000 per vehicle per year, depending on the upgrades over a standard articulated vehicle the bus has. The assumed extra cost for BRT is a result of its train like operation such as dedicated right of way, possible variation in power supply from traditional busses, cost to maintain a fleet that differs from the standard and new emissions and drives technologies.

While it is clear that on a per-vehicle basis, LRT systems are the more expensive, the findings indicate that if the peak ridership demand of the system is 1556 passenger spaces (both seated and standing passengers) per hour or less, then BRT provides a better cost effectiveness than LRT. However, as peak demand (ridership) increases, the LRT system becomes significantly less costly to operate than a bus or BRT system (24% less expensive). BRT costs increase at a constant rate as ridership grows, since each bus needs an additional driver. However, LRT systems only increase in cost when a new driver is needed for an additional train, which is equivalent to 2 to 4 busses. LRT also becomes more attractive and less costly to operate than BRT, as service becomes more frequent and headways decrease, to provide increased capacity. Using the NTD data, as outlined in figure 26, the marginal cost increase for LRT is significantly less than busses or BRT. This gives LRT the advantage if off peak demand is expected to increase in the future, or if ridership is higher than projected.

This data analysis agrees with the previous findings that LRT is less expensive to operate in most cities because it operates in areas of high ridership potential and short headways. The converse is also true; installing LRT systems in areas of low ridership, larger headways and slow growth will make them very costly to operate. In order to determine if Hamilton would benefit from LRT or BRT, solely on the basis of operating costs, this same parameterized analysis could be done for Hamilton specific information. We can also use this research in conjunction with research completed by IBI Group (see the Economic Impact Study – Appendix E) to develop general rules which can guide our decision making.

5.6 Other Research

Additional research conducted by the United States General Accounting Office (GAO) and the City of Houston, Texas, provide additional research comparing the cost of LRT and BRT. According to the GAO, results are mixed when comparing LRT and BRT operating costs. Results varied between cities which could possibly be attributed to the configuration of the transit network, urban planning strategies, types of vehicles used, the financial climate of the region and several other factors. While this evidence does not provide a definitive answer as to which technology is cheaper, it confirms that, depending on the system characteristics, operating and maintenance costs for LRT can be less costly than BRT and vice versa (GAO, 2001)

The Houston Evaluation for Build Alternatives: Major Investment Study/Environmental Assessment, Conducted by the Metropolitan Transit Authority of Harris County, Texas in 1999 found that the benefits of LRT over BRT were quite numerous, while the operating costs were similar (MTAHC, 1999).

5.7 Beyond Operating Costs

The examination of gross operating costs for transit vehicles looks at one aspect of a much larger and more intricate analysis. The net operating costs are of particular interest and depend on a variety of factors, including ridership. In addition to costing data, the projected economic spin-offs, increase in property values, and increase in transit oriented development all play a role in the success of the system and its costs over the entire life-cycle. When analyzing costing data or deciding between two alternatives, the overall benefits of the system will play a much larger role in decision making then a focus on operating costs, especially when these benefits offset the costs immensely.

This analysis focused on gross operating costs in order to examine one piece of the overall puzzle. It identified that at 1800 passenger spaces per hour the cost to operate BRT is higher than the cost of operating LRT. The specific number for Hamilton, in terms of passenger spaces per hour, differx from this value, as it is based on averaged data from a variety of American cities. The study conducted by IBI in appendix E of the economic impact study (2009) puts this “crossover” value at closer to 2500 passenger-spaces per hour for Hamilton.

Overall, it is clear from the analysis that given the proper amount of transit oriented development and ridership numbers, LRT is a viable option as a form of rapid transit for the city of Hamilton.

Figure 26: Costing Data from Eric Brunn's Mathematical Paramaterization Research (Bruun, 2005)

TABLE 6 Trunk Line Service Comparison with Peak Service Added for 6 h per Weekday

Service Condition	h (min.)	*N*	Line Capacity (spaces/hour)	Annual Cost (1000)	Cost per Space-km	If Added Off-Peak	Cost per Space-km
LRT							
Base service	15	5	744	$6,907	$0.038	N/A	N/A
Add 1st car to each consist	15	10	1488	$2,285	$0.054	$470.9	$0.011
Add 2nd car to each consist	15	15	2232	$2,285	$0.054	$470.9	$0.011
Add 3-car train to line	12.5	18	2678	$1,513	$0.059	$424.7	$0.017
Add 2nd train to line	10.7	21	3125	$1,513	$0.059	$424.7	$0.017
Add 3rd train to line	9.4	24	3561	$1,513	$0.059	$424.7	$0.017
BRT $Z = 1.2$							
Base service for equal budget	9.25	8	778	approx. $6,907	$0.037	N/A	N/A
Add to double capacity	4.6	16	1556	$2,524	$0.057	$1,257	$0.029
Add to triple capacity*	3.1	24	2334	$2,524	$0.057	$1,257	$0.029
Same capacity as LRT h = 12.5*	2.68	28	2687	$1,262	$0.057	$628.3	$0.029
BRT $Z = 1.4$							
Base for equal budget	10.6	7	679	approx. $6,907	$0.041	N/A	N/A
Add to double capacity	5.3	14	1358	$2,576	$0.067	$1,466	$0.038
Add to triple capacity*	3.5	21	2037	$2,576	$0.067	$1,466	$0.038
Same capacity as LRT h = 12.5*	2.68	28	2687	$2,576	$0.067	$1,466	$0.038
Tangential bus							
Unit cost for 18-h service	15	1	320	$593.5	$0.056	$593.5	$0.056
Base network costs							
LRT	15	20		$27,600			
BRT $Z = 1.2$	15	32		$27,600			
BRT $Z = 1.4$	15	28		$27,600			
Tangential bus	15	258		$153,100			

*Headway and revenue speed may not be maintainable.

6. Potential Market for Made-in-Hamilton Light Rail Vehicles and Systems

Hamilton has a long history in the steel and manufacturing industries. While the city's economy has become more diversified since the 1970s, manufacturing still plays a prominent role in the city's economic and social development. The newly relocated CANMET Materials Research Laboratory (2010) at the McMaster Innovation Park recognizes the prominent role Hamilton plays in the province's manufacturing industry. The potential use of light rail technology in the City of Hamilton, and across the Greater Toronto Hamilton Area (GTHA) market provides an opportunity for the local manufacturing industry to diversify its manufacturing base and build light rail vehicles (LRVs) and supporting components. This builds on Hamilton's steelmaking base and supporting industries such as National Steel Car.

6.1 Locally Designed and Built

6.1.1 Portland Iron Works

A resurgence of Light Rail and Streetcar projects throughout the United States has sparked interest among key stakeholders to consider developing light rail technologies locally and to facilitate local design and construction. The first effort occurred in 2007 in Portland, Oregon with a $4 million contract to build streetcars similar to the ones supplied by Skoda of the Czech Republic, by United Streetcar, a subsidiary of Portland Iron Works Inc. This streetcar contract was the first of its kind in the United States. However, in Canada, parts of the Vancouver Skytrain and TTC streetcars are designed and built locally by Bombardier (Burnaby, BC, Thunder Bay, ON & Quebec), a Canadian company.

6.1.2 European Experience

Even with the resurgence of rail technology in North America, streetcars are still much more popular in Europe, one of the largest markets for rail technology in the world. The major light rail manufacturers, Bombardier, Siemens and Alstom manufacture most of their trains and components in Europe. Bombardier, a Canadian company, also has manufacturing facilities in Thunder Bay, which make TTC streetcars and components of the SkyTrain. Siemens, based in Germany, has a manufacturing plant in Sacramento California, which builds much of Portland and Calgary's rolling stock. However, there is a large potential to build more LRVs in the GTHA, especially with the province's MoveOntario 2020 initiative currently underway, representing an initial investment of $11.5 billion in rapid transit projects.

6.1.3 MoveOntario 2020, Regional Transportation Plan (RTP) and LRT

The Big Move represents a potentially large light rail vehicle demand when the TTC's Transit City, the proposed Hamilton Rapid Transit system and York Region transit plans are taken into account. In addition, according to the RTP, as the regional transportation system matures and ridership increases, those regions running bus rapid transit (BRT) systems may be considered as potential areas for LRT upgrades. The potential demand for LRT is anticipated to grow, beyond the initial investment, as additional potential LRT rapid transit lines in Toronto and Hamilton are built and Canadian content policies are applied to the implementation of these systems.

6.2 Opportunities for Hamilton Manufacturing

Hamilton's manufacturing base, along with its green energy potential could be coupled together to:

- Work with local steel and manufacturing expertise to design and manufacture light rail vehicles (LRVs) and light rail transit (LRT) system components:
  - Bogies (wheel base, axels, suspension systems, breaking system and drives)
  - Metal track components and wheels
  - Exterior metal/fiberglass/aluminum shells
  - Concrete and polymers for embedded track and power supply poles
  - DC motors for propulsion systems
  - Electricity supply systems and wires
  - Electricity collection systems on-board the train
  - Passenger information systems and display screens
  - Station design and construction with passenger information systems, metal framing, lighting, concrete, local art and advanced urban and transit oriented design features
- Provide engineering services for signaling and train automation systems
- Produce local green energy to supply electricity to the LRT

6.3 An Inclusive Process

Overall, this concept has merit, with extensive potential; however, it requires an in-depth knowledge of the current state of LRT manufacturing on the continent. Companies such as National Steelcar could be leaders in understanding what needs to be taken into consideration when designing manufacturing processes for steel rails and wheels, fiberglass bodies and other key components.

6.4 Fixed Infrastructure means Sustainable Prosperity

Gauging the amount of manufacturing expertise that currently exists in Hamilton is the first step in building a sustainable LRV manufacturing base. Hamilton manufacturers could develop a business case that promotes and builds on existing expertise and its existing capacity to begin manufacturing immediately, distinguishing it from other GTHA neighbors. In addition, maintenance parts for LRVs will be important renewable components to manufacture for all North America's transit systems. The benefit of fixed infrastructure ensures that the market for replacement parts and train body upgrades will be sustained over time. This market is further stabilized by an LRV customer base consisting mainly of local and regional governments or public-private partners.

7. Historical Context of Rapid Transit in Hamilton

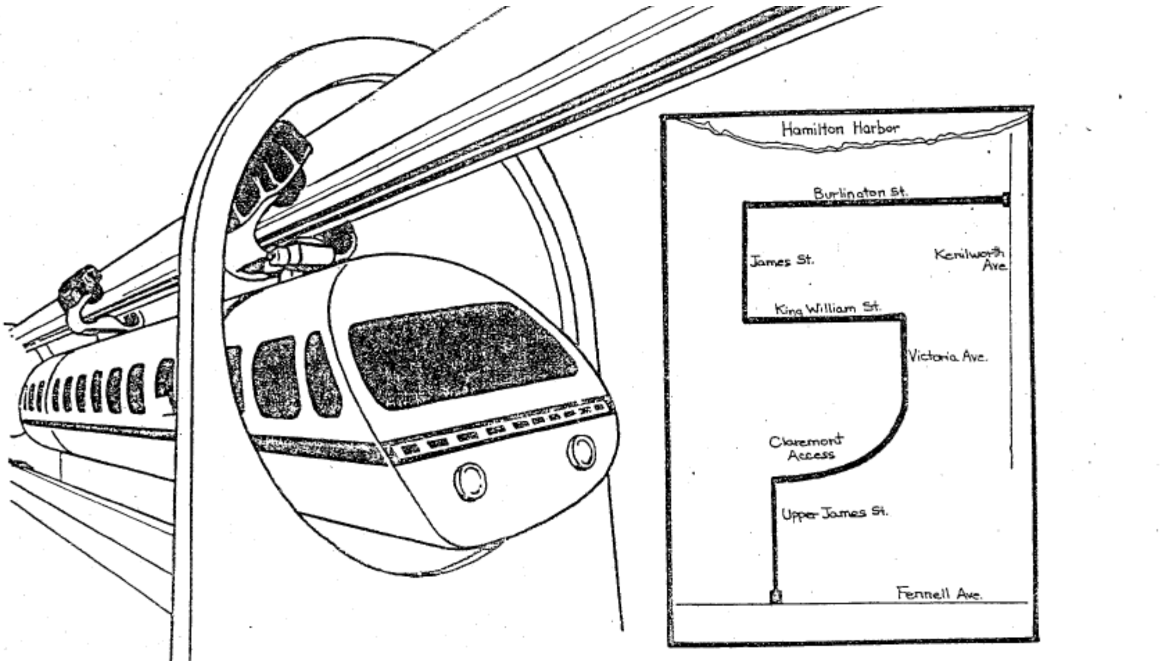
Hamilton has a long history of rail use in passenger, commercial and industrial contexts. The first street car lines in North America were established in New York City during the 1830s. These inter-city rail networks enjoyed great success for many years until the popularity of the automobile began to compete with rail. By the 1950s, most street car networks were dismantled in favour of more flexible buses that were thought to alleviate congestion and decrease the cost of infrastructure associated with the streetcar (Taplin, 1998). The Hamilton Street Railway was dismantled in 1951, in favour of trolley buses powered by overhead wires which, after 1992, were replaced by a bus-only transit network (Wyatt, 2007). At the height of rail passenger transit in the city there were four independently run lines connecting Hamilton's inner city with Brantford, Dundas, Ancaster, Binbrook, Burlington, Stoney Creek and Niagara. These lines served inner-city connections, such as the Hamilton Street Railway, and regional functions, such as the Toronto, Hamilton and Buffalo (TH&B) railway. Most lines travelled East-West along Main, King, York, Aberdeen and Lawrence road. They also ran North-South using Mountain Brow Boulevard and Beach Boulevard to Burlington.

The first mention of rapid transit in Hamilton can be found in a Hamilton Spectator Article from 1962 which states "If the city has built up a well planned rapid transit system, mass transportation moves about smoothly to nurture development of the municipality. If only more buses and automobiles and commercial vehicles are crowded onto existing streets, it can strangle the city's lifelines and end its growth" (Marshall, 1962).

A city report on transportation and transit from 1962 indicated that two North-South lines using James and Ottawa Streets were needed in addition to an East-West line running from Highway 102 (Hwy 403 bridge) to Hwy 20 (Centennial Parkway). For many years thereafter, the two types of systems that dominated transit planning discussions were subways and elevated rail tracks or monorails. Much of this speculation came from the building of Toronto's Younge subway line in the 1950's, the Disneyland Monorail and Seattle Monorail built for the 1962 World's Fair.

Hamilton's drive for rapid transit continued throughout the 1960s and 1970s, resulting in a variety of transportation studies which chose the North-South Corridor as the area of choice for rapid transit, because it was projected to have the highest population growth. This line would run from Mohawk road and Highway 6 to the downtown core via Upper James Street and the Claremont Access, ending at Civic Square (Jackson Square). Another would run from Mount Albion to Barton Street and then onward to the core.

East-West Lines along Main and King from Main St. West (King's Highway 2) to the downtown core were also considered important corridors. These three lines would all meet at the current site of the Hunter Street Terminal. While the technology was not specifically identified, proposals for monorail, subway and light rail transit systems were put forth. This lead to a 1974 plan for a monorail system, promoted by Mayor Victor Copps, which followed the North-South route while using Burlington Street to end at Kenilworth Avenue. It was projected that future expansion would link the airport and the Nanticoke Stelco Lake Erie Works to the downtown core.



HAMILTON

Mountain climber

An artist's sketch shows the design for a proposed monorail transportation system that may link the mountain, downtown and industrial areas of Hamilton within three years. The map shows the proposed route of the monorail that would cover a 6.5 mile route at top speeds of 75 miles per hour. The transportation link would cost the federal government, provincial and city governments about $37.4 million. A second phase of the system would link both Hamilton Civic Airport and the Stelco Nanticoke complex with the city.

Figure 27: Possible Monorail Design ("Monrail Proposal for City", 1974)

The Ontario government's urban transportation policy of the 1970s and their formation of the Urban Transit Development Corporation (UTDC), now the Advanced Rapid Transit (ART) division of Bombardier, enabled the province to fund, design and eventually build a system similar to the original Hamilton Transit Plan backed by Mayor Copps, referred to as ICTS (Intermediate Capacity Transit System). Hamilton was to be a test city for a new rail technology using driverless trains on elevated guideways, powered by linear induction motors and magnetic fields. The cost of the system was projected to be 100 million dollars with 90% of the funding coming from the federal government and the province, who wished to promote a new technology that propelled the train using a middle track and positional wheels, rather than traditional rail methods. This system is currently running in Vancouver as the Sky Train and in Toronto as the Scarborough RT.

The proposed Hamilton Rapid Transit Project of 1981 looked at a variety of corridors connecting the upper escarpment with the downtown core including two tunnelling routes, one starting at Fennel Avenue and Upper James and ending at lower James Street; the other starting at Inverness and Upper Wellington and ending at the start of the Claremont access and the Jolly Cut. The other two routes were to be built above ground using elevated guideways. The preferred route, “W” (see figure 30) was chosen to run from Mohawk Road to the core using a tunnel at James Street.

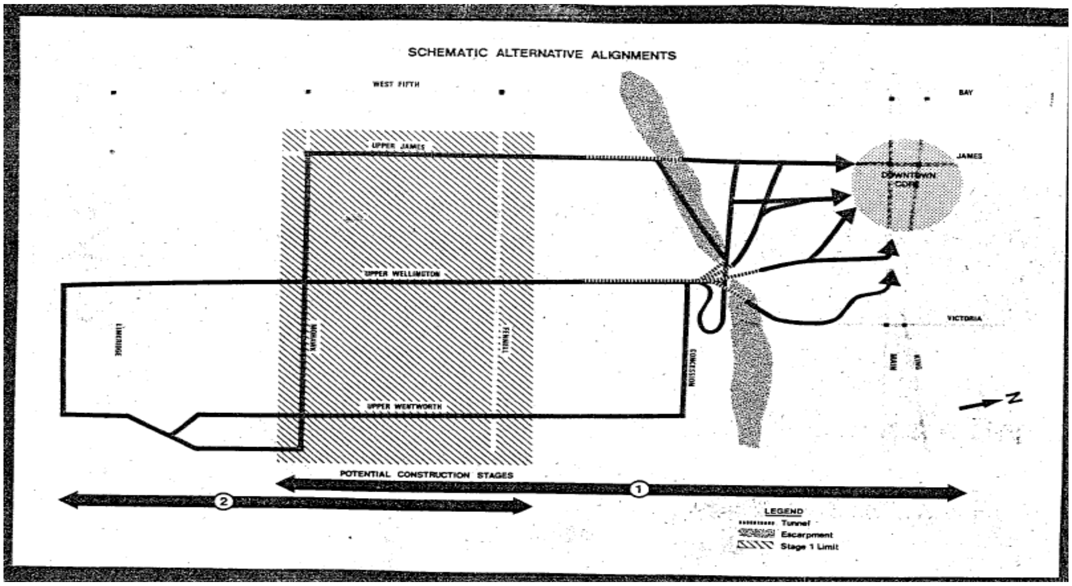


Figure 28 - ICTS Alternative Alignments (Metro Canada, 1981a)

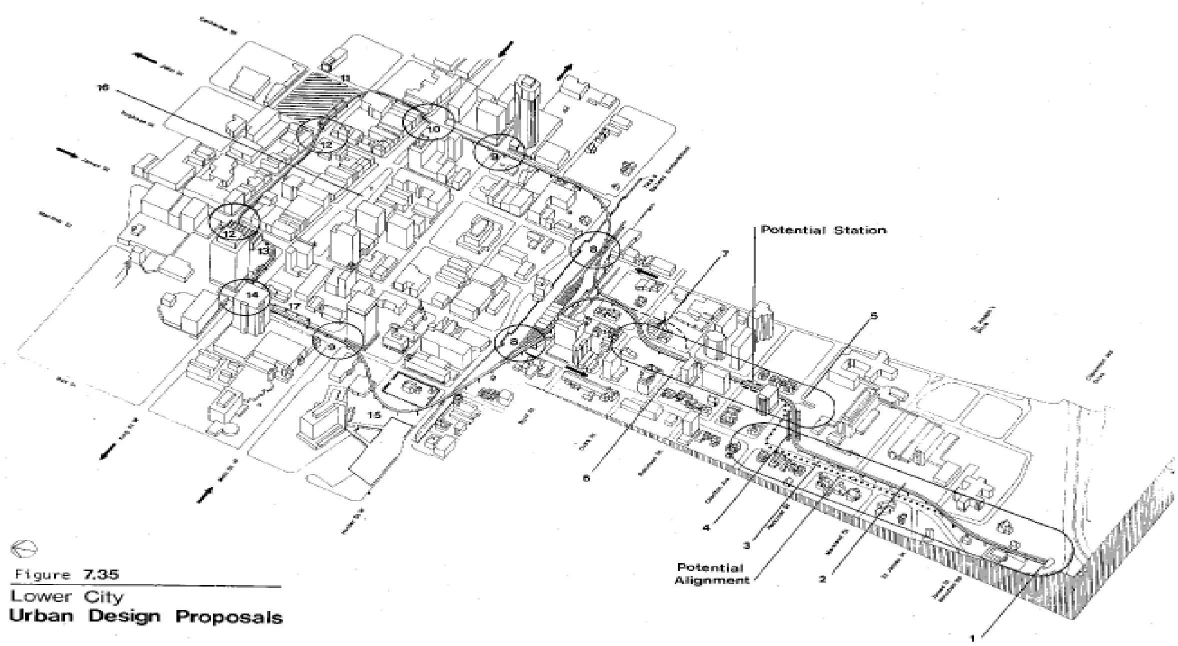


Figure 29 - Diagram of the Downtown Portion of the ICTS (Metro Canada, 1981b)

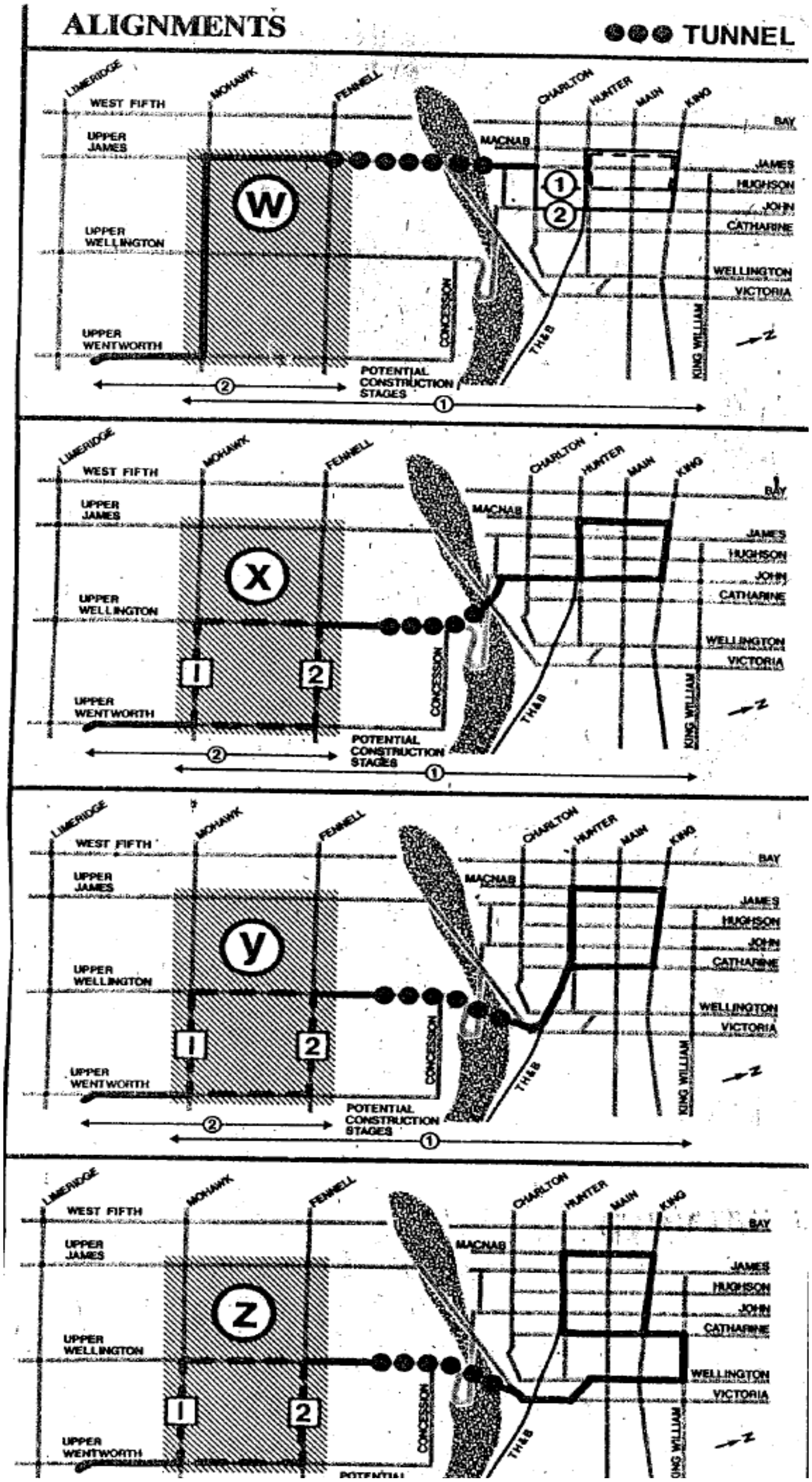
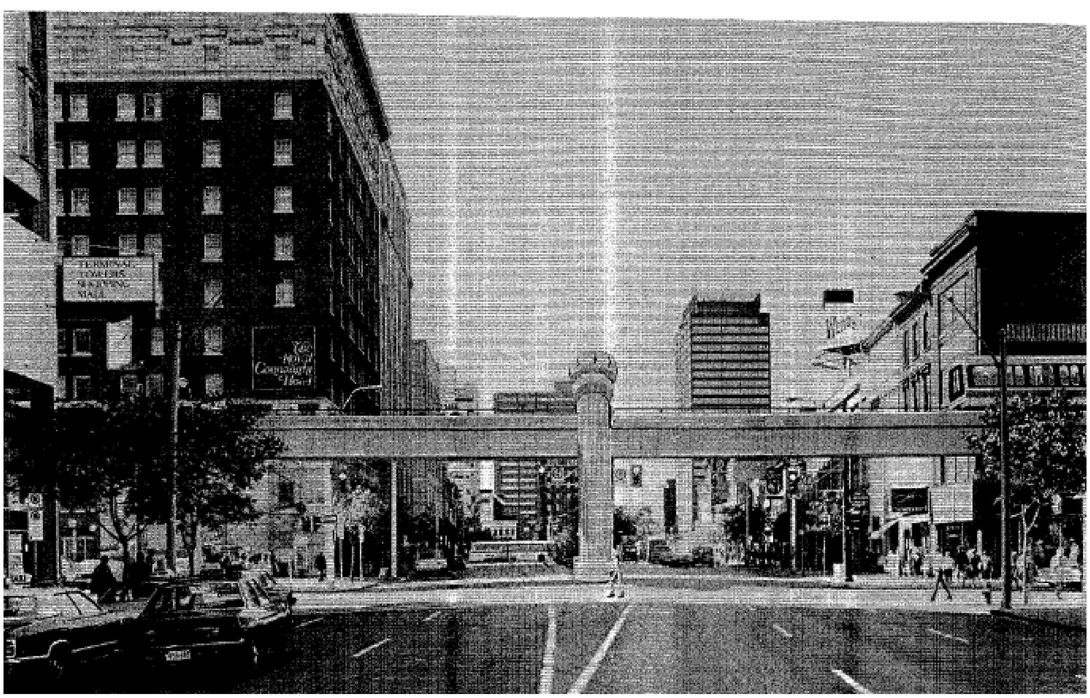


Figure 30 - Four Proposed ICTS Alignments (Metro Canada, 1981c)

An example of the elevated guiderail and car can be seen in artist renderings of familiar Hamilton streetscapes. The first is a view of James Street South at the escarpment tunnel exit:

The second is at the Royal Connaught in the downtown core:



Proposed station stops included Upper James and Mohawk, Upper James and Fennel, St. Joseph's Hospital, MacNab and King William Streets. The elevated track was to be a made-in-Hamilton design comprised of concrete in some areas and composite steel in others. Along the mountain corridor trains would travel along a median guideway carrying two way traffic, and a one way looped guideway as they entered the central business district. Portions of the TH&B lands (at the present day GO terminal) were to be used as a maintenance facility. The full capital costs of the system were determined to be $111.1 million and operating costs were projected to be $3.5 million per year (Sicoli, 1981, June 17). Ridership estimates in peak hour traffic were 3000 passengers per hour in 1986, and in 2001 they were projected to be 6500 passengers per hour.

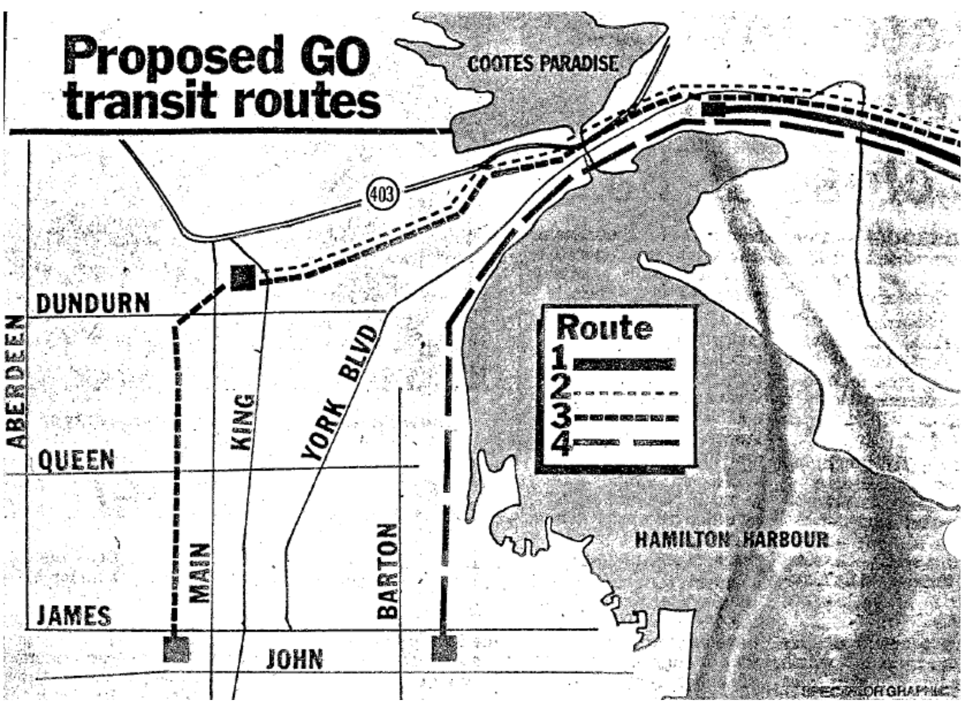
Early on in the transit planning process, during the 1970s, citizen and political support for the system was high; however as the more detailed planning and public consultation processes began in the 1980s, public opinion changed and support for the system dwindled, until the plans were eventually dropped in December of 1981. Some of the concerns included:

- Unsightly elevated guideways
- Negative impact on property values
- Burden on the taxpayer, especially due to unknown operating costs of the system (Rapid Transit Load Will Fall on City, 1981).
- Lack of political will, leadership and organization where rapid transit was concerned
- Improper timing and lack of need as transit needs are well served by bus routes.
- Population growth projections were too high.
- Coalitions of neighbourhood associations against the system.
- Reliance on un-proven, experimental technology.
- Insufficient access for the disabled.
- Traffic, emergency and personal safety hazards due to concrete guideways.
- The UTDC cars were to be made in Vancouver and not in Hamilton.
- Bus routes may still be required along ICTS routes since stations are too far apart.
- Bus routes require upgrading before money can be spent on new infrastructure.
- Does not service the proper areas such as the bayfront industrial core, which have a higher transit demand.
- Poor public engagement/consultation and an inability to answer to citizen concerns, coupled with reports of failure to provide accurate, unbiased reports on public opinion (Sicoli, 1981, Sept. 15).
- Distrust of the province's intentions and the ability of the UTDC to deliver on their promises of prosperity and system functionality.

In addition to these concerns, Hamilton Wentworth Regional transportation planners stunted the new transit system's planning and installation by ranking it 8 out of 13 essential transportation projects for the city, far down the list from the top which contained mostly freeway projects including the Red Hill Valley and Lincoln Alexander Parkways ("Report Says No Urgency", 1981). However, others believed that "rapid transit will be the thing of the future. We can't keep constructing roads and carving up the escarpment for more automobile accesses." (Scicoli, 1981, May 2).

While the UTDC was not interested in alternative technologies, some groups promoted more flexible streetcar systems, such as Edmonton's light rail transit system. From the 1960's to the 1980s ideas of transit options became more conservative and practical. Today LRT dominates transit planning as the most promising and flexible option, because of its ability to travel on street level, allowing for car and pedestrian crossings.

In 1982, the province proposed GO Advanced Light Rail Transit (GO-ALRT) improvement plans for the Oakville-Hamilton corridor. UTDC technology would provide the infrastructure and citizens had input on routing. Three possible routes were identified as feasible. The first was the York Blvd. Elevated Option, where the train travels at ground level East of the CN tracks then is elevated along York Blvd. to a station between Hughson St. and Catherine St. at John St. In the second proposed route, the train travels at ground level west of Hwy. 403, then underground beneath the Hamilton cemetery and Woodbine street, emerging at Locke St. and running across an elevated guideway along York St. to the John St. station. The third proposed route runs at ground level East and North of the CN tracks, then rises over the tracks and runs on an elevated guideway up Ferguson Ave. and end at Wilson St. near James St. (Johnston & MacPhail, 1984).



Public opinion in this case was similar to that of the rapid transit plans two years earlier. In addition, much of the public wondered why a route utilizing the TH&B terminal and tracks was not being considered as feasible by the study team. In both the 1981 and 1983 rapid transit proposals, stakeholders with one-sided, specific agendas were quickly formed, the largest of which was COST (Coalition on Sensible Transit). In the late 1970s, evidence of increased economic and social development where light rail lines were installed was well documented and commonly understood by municipal planners, large businesses and others in the transit field. An examination of citizen letters in the Spectator from this time period shows a lack of interest in transit oriented development and a focus on “Not in my Backyard” politics (Martin, 1984).

A sizable portion of the public was opposed to the GO-ALRT preferred route along York St. and the Woodbine tunnel (under the Hamilton cemetery to Locke St.), but the plan was endorsed reluctantly by council. At the same time, the federal government created new legislation requiring existing rail corridors to be shared with commuter rail traffic. With this assurance the province opted to scrap GO-ALRT plans in favour for the conventional GO Transit system that is in place today. Currently, Hamilton has five GO-Train trips per day (a morning train to Toronto and four evening trains to Hamilton).

8. Conclusion

This analysis provided an investigation of the technologies associated with light rail rapid transit infrastructure in order to:

- Examine light rail infrastructure, rolling stock, power systems and operational aspects
- Provide an in-depth investigation of potential LRT technical challenges in Hamilton
- Investigate technologies that may be able to address Hamilton’s geography and planning constraints
- Investigate the operating and maintenance costs of these technologies
- Examine the historical context of light rail technologies in Hamilton
- Develop a basis to guide further planning and design research
- Develop recommendations and considerations for further planning and construction efforts

This study is intended to compliment a variety of other investigations conducted by the city including the Economic Potential Study, Community and Economic Impact of Light Rail Transit, Functional Planning Analysis, RTFS Phase 1 and 2, LRT Subsurface Impact Assessment and Costing Analysis. This paper, along with the other studies listed, provides a basis to guide further planning studies.

The results of this analysis clearly indicate that many of the technical challenges of implementing light rail transit systems in various corridors of the city can be overcome. Furthermore, it demonstrates that LRT technology is a feasible and efficient transportation mode for the city of Hamilton.

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10. Appendix A: LRT System Types

LRT System	Description	Example
Modernized tramway	These systems usually have shared or reserved, and in some sections also segregated, right-of-way; they run through pedestrian zones and have priority treatment at junctions.	Amsterdam, Oslo, Zurich and Vienna.
New tramway systems	Based on low-floor vehicles, are well integrated into the townscape and a considerable part of the network is segregated from other traffic.	Grenoble, Strasbourg and Valencia.
Evolutionary LRT systems	Upgraded from trams, having segregated right-of-way over long sections or even underground exclusive right-of-way.	Other examples are Gothenburg, Hannover and Rotterdam.
New LRT systems	Similar to Evolutionary LRT systems. Since they cannot use old tracks they usually consist of only a few lines. This is the most common system used in North America, and is the system under consideration for Hamilton.	Calgary, Edmonton, Portland, San Diego, Utrecht, Sheffield, Tunis, Kuala Lumpur and Sydney
Mini-metro LRT	Fully grade-separated systems that usually include underground sections in the inner city. This can reduce system flexibility while increasing system efficiency.	Copenhagen
GT-type LRT systems	Automatically guided and operated, with exclusive right-of-way within their whole networks; reducing system flexibility. (system considered by Hamilton in 1981 Rapid Transit Project)	London Docklands, Lille and Vancouver
LRT- regional rail integrated systems	Use railroad tracks to expand service into the region. They can be based on a tram system as in Karlsruhe or represent transitional forms towards a metro system.	Manchester
Regional Rail on tram tracks	A railroad vehicle is adjusted to run on public streets. Regional rail service, with light vehicles, is to be connected by tram tracks directly with the city centre.	Zwickau, Germany
Rubber-tire Tram way	Developed by Alstom, these systems are usually metro type systems, but run on rubber tires and steel track.	Paris, Mexico City
Track-guided rubber-tire tram	Was developed by Bombardier in 1997. It is supposed to combine a tram in the inner city with the flexibility of a bus at the periphery. It is guided by a monorail and supplied with electricity by overhead wires.	Potential in Caen, France.

(Adapted from Topp, 1999)

11. Appendix B: Comparison Between Potential Hamilton Vehicle, TTC Streetcar and the Portland Streetcar

This appendix compares the proposed Hamilton standard vehicle described in section 3.1.1, the TTC's CLRV streetcar and the Portland streetcar. This comparison will help the reader understand the differences between these three vehicle types and allow for a quick comparison.

Specification	Hamilton Proposed	TTC Streetcar	Portland Streetcar
			
Manufacturer	To be determined	Bombardier (Canada)	Skoda-Inekon (Czech Republic)
Model	To be determined	CLRV	T10
Train Type	100% Low Floor	High Floor	70% Low Floor
Track Gauge (Standard)	1.435 m	1.495 m	1.435 m
Vehicle Weight (Empty, average)	41, 000 kg	22, 685 kg	24, 200 kg
Vehicle Weight (Full, average)	63, 000 kg	29, 685 kg	39, 740 kg
Power System	Catenary-Pantograph	Trolley Pole	Catenary-Pantograph
Single Vehicle Height (without pantograph)	3.5 m	3.6 m	3.46 m
Single Vehicle Length (average)	28 m	15.4 m	20 m
Single Vehicle Width	2.65 m	2.54 m	2.46 m
Passengers (seated/standing)	60/130	46/123	40/134
Total Passengers	190	169	174

12. Appendix C: Rapid Transit Community and Technology Interview Summary

A variety of cities, regions and companies were interviewed to help supplement the research contained in this analysis. Following is a list of these groups and the questions that were posed to them.

12.1 List of cities, regions, and companies contacted:

Cities	Date
Cities Interviewed	
Minneapolis, Minnesota	July 30, 2008
North County, California	July 30, 2008
Halifax, Nova Scotia	July 31, 2008
Buffalo, New York	August 1, 2008
Kenosha, Wisconsin	August 26, 2008
Edmonton, Alberta	August 27, 2008
Cities Visited	
Charlotte, North Carolina	September 2, 2008
Portland, Oregon	September 3, 2008
Calgary, Alberta	September 5, 2008
Companies Interviewed	
Siemens	December 18, 2008
Bombardier	January 20, 2009
Alstom	March 12, 2009
Cities Contacted	
Toronto, Ontario	Various dates
Ottawa, Ontario	Various dates

12.2 Questions for Discussion with North American Municipalities

System Planning

1. What was the key driver that led you to implement Rapid Transit? How many types of vehicle technologies did you evaluate before making a decision? How did you come to your decision?
2. What was the best thing you did during your Rapid Transit planning process?
3. What would you say is the most important lesson learned from your Rapid Transit planning process?
4. How did you select the corridors of your first Rapid Transit route? (i.e. existing rail, potential/existing land use, nodes, cost) How did you select the start and end nodes?
5. Was the project staged? If so, where and why was the project staged and what were the economic disadvantages/advantages of doing so? How was the project constructed? All at once or in pieces?
6. Has there been or are there plans to further extend your city's rapid transit system as a result of introduction of a rapid transit line? Is the estimated ridership in line with predictions?
7. How do the operational costs of the rapid transit system compare with the operational costs of a typical transit system?
8. What were your modal splits before and after Rapid Transit Implementation?
9. Do your rapid transit corridors have mixed uses on them including Rapid Transit, bike lanes, automobiles etc? What was the street network like prior to rapid transit i.e. one-way or two-way? Has the implementation of rapid transit affected other modes of transport such as walking and cycling? Were such facilities (walking paths, bike lanes) integrated with the development of the rapid transit line?
10. Are there any environmental concerns?
11. Is your rapid transit system managed by the same group that manages conventional transit in your municipality?
12. How many km/miles of Rapid Transit routes do you have?

Operations

13. Many "textbook'" standards use 400 metres (1/4 mile) as the average walking distance people will travel to access higher order transit. Has this been the case in practice? (i.e. how far out from the line has rapid transit had an impact)
14. How have parking issues been handled along the rapid transit corridor? Has it been restricted? Removed? How have deliveries and loading been accommodated for businesses in older build up areas? Has the zoning along the transit route changed (if at all)?
15. Are there any negative impacts on existing businesses i.e. impede deliveries, etc.?
16. How has the rest of the transit system been impacted by the introduction of rapid transit? Has local transit been re-routed to act as a "feeder" system for the higher order transit?

Land Use Planning

17. When new rapid transit corridors were established was the density to support transit already in place or did the density get built up after the establishment of the transit line? (i.e. what did your corridors look like before rapid transit and what kind of transformation took place and how quickly?)
18. In your municipality's experience, what has come first, the rapid transit or the development? Has there been a situation where rapid transit preceded widespread land development or was rapid transit only a response to development? Have you had experience with building rapid transit prior to widespread demand and encouraging development as a result? If so how was this achieved?
19. There are many differences between implementing higher order transit in greenfield areas versus in older built up areas. Where rapid transit was planned and built in older built up areas, what challenges and unique situations were encountered? What were the additional considerations? How was the rapid transit line integrated with existing buildings so as to not adversely impact the unique characteristics of the area?
20. After the implementation of a rapid transit system how has land use planning changed (if at all)? Is there more emphasis on encouraging intensification or has the market taken over? Are there any incentives being offered to developers? Who is providing the incentives and what do they look like?
21. How was/is Transit Oriented Development utilized along the corridor?

Economics

22. After implementation of a rapid transit line, has there been an increase in investment near and adjacent to the transit line and/or transit hubs/stops? Generally, how far from the transit line and/or hub has this investment occurred? What if any types of development investments have been made (residential, commercial, mixed use)?
23. Was there a positive impact on tax revenue from increased development, if any, with respect to the installation of rapid transit?
24. Have property values been affected by the development of rapid transit. If so, what type of impact did the development have? Was there a certain distance from the transit line or hubs in which property value increases (if any) tapered off?
25. What is the cost-benefit of implementing the service?
26. What is the return on investment for same?

Tourism

27. Was tourism considered in rapid transit planning? Has tourism benefited from having a rapid transit system in place? Has rapid transit helped an entertainment district in your city grow?

Communications

28. How important was public consultation and outreach as part of your Rapid Transit planning process?
29. What communication methods did you employ during your public consultation process? What worked well? What would you do differently? Did you find that the public consultation process only attracted a certain demographic, or was a broad cross-section of the population active in the process?
30. How did you engage the business and/or development community? Were they supportive of Rapid Transit?

12.3 Technology Related Questions for Vehicle Manufacturers

1. What track gauges do you support? Are there differences in vehicle cost?
2. What is the standard weight of your vehicles? Are there any accommodations that need to be made to handle a vehicle of certain weight (ie. roadway improvements)?
3. What are the standard vehicle dimensions? What changes a vehicle dimension?
4. What are standard vehicle amenities? What is recommended?
5. Are there any specifics when dealing with low floor accessibility? Bike racks?
6. What is the height of the centenary system? Can it be varied throughout the track corridor or is it always constant?
7. What power supply would you recommend for the City of Hamilton? Third rail or catenaries? Are there manufacturing cost differences?
8. What are the power system requirements for your vehicles in terms of voltage, current, transfer stations, etc.
9. What type of vehicles do you produce/use? Can we get technical specs for each?
10. What are some of the overhead wire constraints (ie. the minimum height required to operate the catenaries and pantographs)
11. What are some of the subsurface infrastructure constraints (ie. reinforced concrete roadways under the track, removal of water mains/sewers, relocation of utilities)?
12. What types of technologies/techniques are used to mitigate vibration issues?
13. Are there any particular station needs or issues with inclement weather?
14. Do you provide an integrated solution such as a train monitoring and information systems, power systems, fare collection and transit priority signaling?
15. Is a new traffic control system necessary? Can an existing system be used or should it be updated for transit priority signaling?
16. What is your policy on maintenance facility, parts and service?
17. Do you have any specific suggestions on technology matters to consider at this early stage of our process?