

A photograph of a train moving through a tunnel, captured with a motion blur effect. The train's headlights and interior lights are visible, creating streaks of light. The tunnel walls are dark, and the floor has a yellow and black checkered pattern.

Transit Technology Choice Report

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October 19, 2009

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Prepared for

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October 19, 2009

TO3063

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Executive Summary

The selection of the appropriate rail transit technology for the City of Ottawa is a major component of the 2008 Transportation Master Plan (TMP) process.

A selected rail transit technology must:

- Accommodate the predicted passenger volumes: Ensuring that operational efficiency and running costs are optimized.
- Provide conditions to easily implement the first increment and all subsequent phases of the system.
- Fit into Ottawa's urban environment: Ensuring that the vehicle and system design are a good fit with the city's image and have a reduced environmental impact.
- Minimize capital costs: To ensure that stakeholders and citizens have a good return on investment.
- Minimize the lifetime operating and maintenance costs: Ensuring low ticket prices and encouraging ridership.
- Be able to respond to future land use changes within the City and the demand for travel: Providing flexibility of operations to accommodate future city planning and operational changes.
- Take advantage of the most current technologies: Providing operational efficiencies and subsequent lower operating costs.
- Be proven in service: Minimizing risk of development and increasing operational reliability.
- Be suitable for the climate in Ottawa: Ensuring that the vehicle can withstand the extremes of temperature.

A study has been undertaken to advance this component of the TMP process and finalize the technology selection which began with the Technology Workshop held in June 2009. The primary purpose of this work is to develop a clearer set of technology parameters and provide information on how the proposed rapid transit network, projected ridership levels and the technology characteristics of different rail modes interact.

Key Discriminators

The key discriminators for the rail transit technology choice include:

- Transit System and Network Integration, including the impacts of multiple transportation modes on:
 - Transfers for passengers
 - Fleet management, including deadheading, with multiple unconnected operations, maintenance and storage facilities
- Impacts of segregation
 - Cost of segregation
 - Impact of an alignment through the Greenbelt

Passenger Volumes and Predicted Ridership

The TMP planning process was supported by a regional transportation model that projected future(2031) transit ridership through the downtown of Ottawa would reach 14,400 persons per hour per direction (pphpd) between Bayview Station and the future Downtown West Station (to be constructed as a part of the Downtown Ottawa Transit Tunnel project).

Additional volumes of passengers emanating from the N-S Line and the STO routes from Gatineau could increase potential volumes to 20,000pphpd should any future interprovincial rapid transit link feed into the planned TMP network west of the downtown. Based on this, and to provide an adequate spare capacity to accommodate future growth beyond 2031 and for the purposes of the technology selection, the ultimate capacity is considered to be 24,000 pphpd. It should be noted that for reasons of development constraints, the core may not increase beyond this ridership capacity.

Based on the above a number of different technologies were evaluated for suitability. Some technology choices such as monorail and heavy rail were discounted based on the evaluation criteria.

To meet the predicted ridership two generic system technology choices were considered more suitable to the City of Ottawa and carried forward for further evaluation:

- Light Metro (as in the Skytrain system used in Vancouver or the Mini-subway as used in Kobe Japan) is more operationally suited to development in the downtown core, and
- Light Rail (LRT) (as used in Calgary or Minneapolis) is a better selection for urban planning and implementation outside of the main core, while also being able to operate in the main core.

The combination of Light Rail Vehicle with a CBTC system to provide 20,000 pphpd has not yet been proven in revenue service.

#	Criteria	Description	Light Metro	LRT	Driver operation (ATC manual)	Automated (Non-manual ATC)
1	Maximum passenger capacity in the core	>20,000pphpd	Best	Fair	Poor	Best
2	Low passenger capacity in the extensions	> 5,000 pphpd	Good	Best	Good	Poor
3	No more than one transfer and no in-line passenger transfers		Poor	Best	Required	Not applicable
4	Ability to build a non-segregated system in low density areas		Poor	Best	Required	Not applicable
5	Comparative total system capital cost	all Phase 1 network, infrastructure and vehicle fleet	Good	Best	Good	Fair
6	Comparative life time operating and maintenance costs	all Phase 1 network, infrastructure and vehicle fleet	Best	Good	Poor	Good
7	Proven in service	At least five years in revenue service	Good	Good (Note 1)	Good	Good (Note 1)
8	Suitable for the climate in Ottawa	Operated in a climate similar to that of Ottawa	Good	Good	Good	Good

Note 1: In order to meet the 2031 core capacity requirement, the vehicles associated with the LRT system will require operation with less distance between them. This requires a more modern Automatic Train Control (ATC) system such as the Communications Based Train Control (CBTC) system.

A key finding of the report is that the choice of technology determines the future flexibility of a transportation network within Ottawa. By developing a Light Metro style system, the core will meet its capacity prediction targets and have sufficient margin for growth beyond the prediction; but the report finds that the potential capacity within the core may not warrant such a system.

The implementation of a high capacity light metro style system may divide Ottawa's transportation network into a set of fragmented, unconnected and disparate transportation modes, which will multiply staff costs, overheads, maintenance and spares and maintenance facilities. This fragmentation will also cause numerous onward transfers between transport modes for daily passengers moving into the core from the suburbs.

The choice of a Light Metro system will effectively increase transportation costs due to higher costs of segregation for the outlying suburbs, which may result in lower efficiencies of running and potentially higher ticket costs.

In contrast, the report assesses the corridor with an LRT system which permits a more efficient capacity match for the ridership prediction throughout the main core and outlying regions.

The LRT system provides capacity for the main core but will necessitate some development of automatic operation to maintain operational efficiency at the end of the planning period and beyond. With this automation there will be some consequential development risk of migration of technology to the Light Rail Vehicle (LRV), but this should be balanced with the fact that any technology implementation within Ottawa's climate will carry some residual development risk for manufacturers and integrators. However with the additional implementation of an automated system, the initial capital costs for both LRT and metro may be offset with a reduction in long term operating costs.

A hybrid version of driver operated/automated LRT provides long term flexibility to transit network planning and the possibility of on-street running, a lower cost segregated corridor and the reduced complexity of driver operation in the suburbs. More importantly the passenger is provided with minimal onward transfers when commuting: a key element in attracting ridership.

Light Rail is recommended as the technology choice for deployment in Ottawa as it:

- Provides the necessary capacity for the ridership predictions in the main core,
- Can accommodate low passenger capacity in the extensions outside of the main core,
- Results in less fragmentation of the network, reducing the need for onward transfers,
- Has less impact on the urban fabric and allows the ability to build a non-segregated system in the Greenbelt,
- Has comparative total system capital costs with Light Metro,
- Has comparative life time operating and maintenance costs with Light Metro,
- Allows better integration of technology for the Carling-Lincoln Field's corridor.
- Provides greater network flexibility and promotes development of the transportation network in the core,
- Is a proven design, and
- Is more suited for the climate in Ottawa.

1. Introduction

The primary objective of this report is to identify or estimate network requirements which will determine a suitable transit technology choice and lead to a technology choice recommendation.

As outlined in the TMP, the report assesses a predicted ridership capacity until 2031 and the impacts of an area identified as the 'main core'; which is situated between the stations of Baseline and Blair. It also assesses the wider impacts that a particular technology choice will have on the overall network beyond 2031.

The report summarizes the research conducted into the technology decisions and implications in other cities, and the conclusions drawn from the research. It also examines the major system characteristics and evaluates the suitability of various technologies to the Ottawa situation. Through a series of meetings and a half-day workshop the selection technology was found to rest on the answers to three basic questions:

- What is the ultimate capacity needed through the downtown?
- What degree of segregation is required from other traffic to provide the required reliability?
- How can we future-proof the system to protect future generations knowing the form of the ultimate network?

1.1 What is the Ultimate Capacity Required Through the Downtown?

This has largely been answered by the work conducted by the TMP. The regional transportation model that was used in the TMP work indicates that the 2031 ridership through the downtown indicates that there is a substantial volume of passengers originating in Gatineau that could increase this number to 21,000 to 22,000 pphpd, if the proposal to remove all STO buses from downtown Ottawa goes ahead. This 2031 estimate is not the ultimate ridership level that will be reached, but given the dense urban core, the height restrictions on new buildings in the core and the desire to intensify nodes along the line rather than focus on a single urban centre, the ultimate capacity that is needed appears to be in the range up to 24,000 pphpd.

1.2 What Degree of Segregation is Required From Other Traffic to Provide the Required Reliability

The degree of segregation from other traffic has a substantial impact on both the carrying capacity of the system and the level of reliability of the service. As with the current Transitway, the highest quality service is provided where transit vehicles operate without any interference from other vehicles or pedestrians. Complete segregation from other vehicles is also required for the more complex operating systems as many automated systems do not have an operator on-board who is controlling vehicle movement. As a minimum the core of the network, which carries the highest volumes and has the highest demand for reliable service, needs to be fully segregated. In the outer segments of the network the requirement for complete segregation is less necessary as the longer distances into the core and the lower passenger volumes make the service less vulnerable to service interruptions caused by the interaction with other vehicles.

For the purpose of this study, the ultimate rapid transit network has been divided into three categories:

- Core Network – from Baseline to Blair Stations.
- Extended Network – including future extensions to the rail network as well as the corridor south of Bayview (the O-Train line) and the future connection to Gatineau.
- Secondary Network – including all remaining BRT Transitways, transit priority routes and surface-operating rail routes such as the proposed Carling and Rideau-Montreal Road corridors.



Figure 1 - Core Network

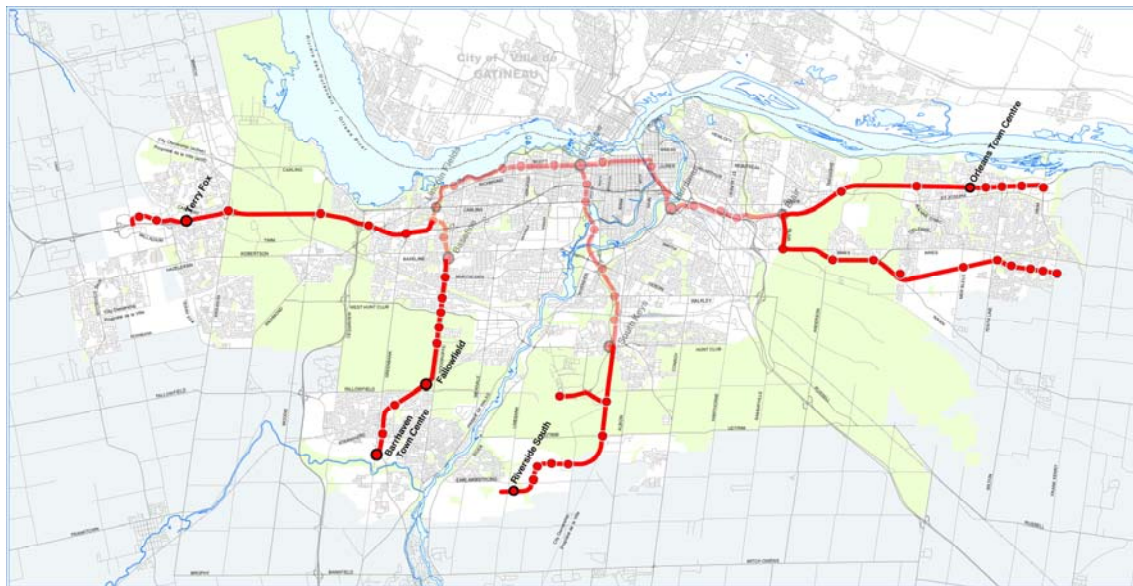


Figure 2 - Extended Network



Figure 3 – Secondary Network (Carling – Lincoln Fields)

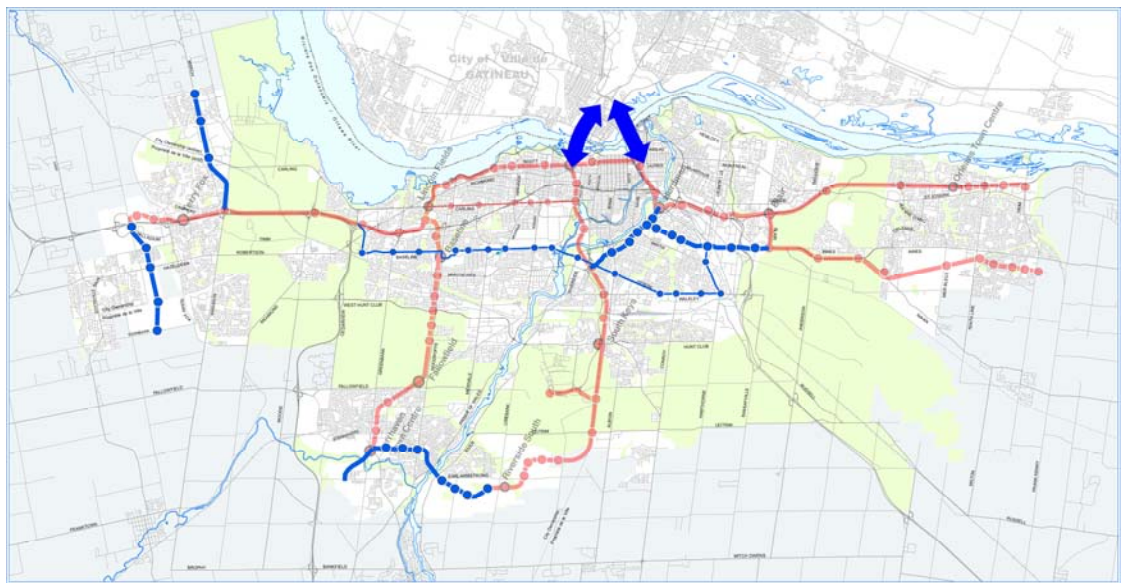


Figure 4 - Secondary Network (BRT Routes)

The requirements for each of these network categories will be slightly different, however there are also several considerations that span between networks and may increase overall capital and operating costs if not carefully considered.

The current TMP does not recommend extending the rail system across the Greenbelt to any of the outer urban communities before 2031, but recognizes that there may be potential to do so at some time in the future. The TMP allows for this expansion under a strict set of guidelines, intended to demonstrate that ridership potential, cost efficiencies, adequate densities around stations and funding are in place. These extensions form part of the Extended Network, and there are substantial issues with extending service out to these areas, many of which will be influenced by the transit technology choice.

1.3 How Can We Future-Proof the System to Protect Future Generations Knowing the Form of the Ultimate Network?

In addition to addressing the issues we know today, we must also consider a range of possible future developments and determine if the choices we make today will still be appropriate. Future-proofing the system requires that we look for a solution that protects for, or is compatible with, the largest number of future scenarios. There are several possible future developments which have not been explicitly examined as part of the TMP, but which may influence technology choice, including:

- Mode split to existing employment increases dramatically (for any number of reasons including increased costs for travel, GHG emission reductions, reductions in personal automobile travel, policy changes that increase parking costs or decisions to limit parking supply),
- Substantially more development along the line than is predicted, with subsequent increased travel demand (both travel destinations at employment centres and travel origins at residential development),
- Development continues along current trends with dispersed employment throughout the region, and low density suburban expansion,
- The height restriction in downtown is relaxed and a new generation of buildings are built that contain far more jobs than the current office towers, and
- Downtown continues to be the focus of job growth, but the height restrictions require a larger downtown built to densities similar to the existing core (likely to occur to the west through LeBreton Flats and to the south of the current downtown).

Each of these potential scenarios will require a different future network, but they can be grouped into two major groups:

- One group will focus more travel on the downtown and put more pressure on the peak periods. These options are more suited to technologies that can provide high passenger volumes at the core of the network, but which are expensive to extend out to the suburbs.
- The other group will require longer commutes to and from more distant places requiring a larger network but a lower peak point volume. These options are more suited to technologies that can provide flexible service at lower volumes to more places and can more easily be integrated with existing development plans and extended out to the suburbs.

2. Travel Demand

The Transportation Master Plan (TMP) used the forecast population and employment for the City of Ottawa to develop estimates of travel demand on the proposed rapid transit network. The traditional four-step transportation planning process was applied using the City's calibrated model, and reflects travel patterns and behaviours captured in the 2005 Origin-Destination Survey.

As part of the TMP work, various networks were tested, with the recommended network providing good coverage of the City, and balancing the cost of implementation with the improved mobility and accessibility provided by a rail-based rapid transit network supported by BRT Transitway and supportive transit priority corridors and local bus services.

Figure 5 Illustrates predicted travel demand for the 2031 raid transit network. As expected the largest volumes are found in the downtown area. This reflects the fact that the downtown remains the major location for employment, and the network is focussed on providing service to this dense area. The network also requires people travelling across the City to pass through the core, increasing demand further.

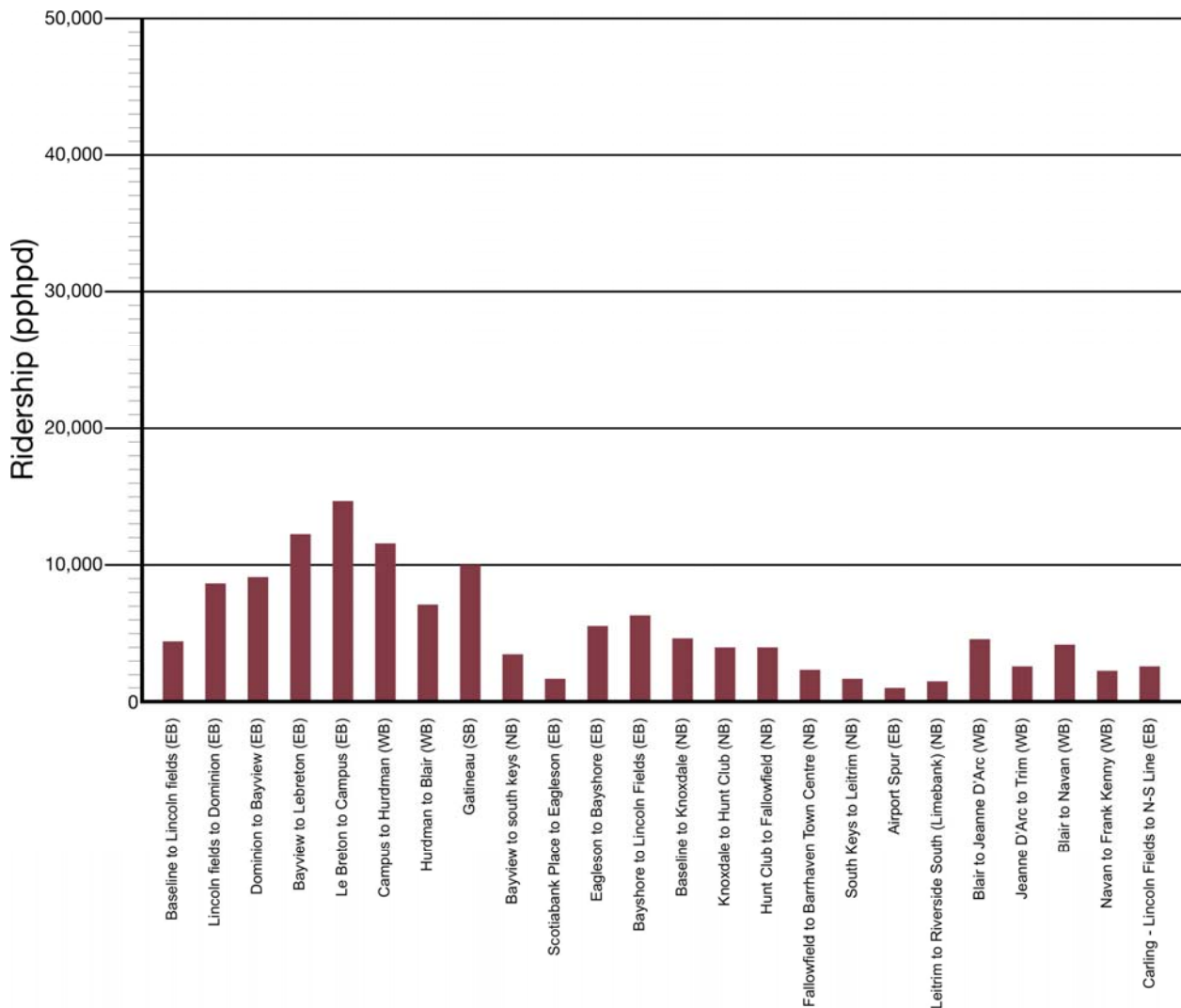


Figure 5 - Travel Demand Predictions (2031)

From the table it can be seen that there are three segments that produce high ridership for the main core and present the highest demand levels anywhere in the network. Developing a service that will adequately respond to this demand level is the most important criteria to planning a network. The three segments are:

- Bayview to Le Breton,
- Le Breton to Campus, and
- Campus to Hurdman.

Bayview to Le Breton – Development of the lands around this station have been assumed in the model. Ridership is predicted to be 12,100 in the eastbound direction. Some additional employment could occur at this station, which could increase ridership levels to beyond the predicted 12,100 however expected planning constraints will limit population numbers in this area. Additional development in this segment will also increase ridership in the Dominion to Bayview segment.

Le Breton to Campus – The future population and employment scenario yields a ridership prediction of 14,400 pphpd. This volume however, does not include the ridership coming into the downtown from Gatineau. The ridership associated with the interprovincial crossing could increase the ridership demand in this segment to approximately 20,000 pphpd, if STO buses do not travel through downtown Ottawa and Gatineau customers are required to transfer onto the Ottawa system. The ridership demand of 20,000 pphpd is an agreed value derived from discussions at prior meetings and is based on modelled ridership data and the practical experience of other network operators.

The Gatineau ridership is the largest risk in determining the required core capacity and operating scenario for the network. A parallel study is looking into potential interprovincial connections however there is no preferred solution at this point. The demand of 20,000 pphpd would be achieved if all passengers from Gatineau are transferred onto the rail network to access the core (and all of the STO buses are kept out of the core).

The area around the Downtown West (Lyon) Station is highly developed and as a result the ridership is unlikely to exceed the 2031 limits, given the restriction in building height and the catchment area in a 300-400 metre radius around the proposed station. To exceed the ridership, significant riders would have to either walk or commute further distances from the south, east or west of the station or the interprovincial crossing ridership increase beyond predictions. Any potential increase in the core can still be managed by careful planning of population densities in the core.

Campus to Hurdman – The ridership is predicted at 11,600 pphpd. Growth in the segment is limited by the development of the University, associated campus and buildings, Highway 417 and the Rideau River. Growth of the south campus area, with the redevelopment of the Algonquin College site will attract some new trips however the majority of university-bound trips are outside the traditional morning peak hour.

Redevelopment of the Sandy Hill Arena area may contribute to additional ridership, but the majority of this development has been included in the 2031 forecasts.

Lincoln Fields Station – Ridership east of the station is predicted at 8,000 pphpd, however west of the station ridership is predicted at 4,400 pphpd. This substantial drop is related to the transfer of rail riders to the Transitway serving Kanata. In effect, ridership splits at Lincoln Fields into two nearly equal branches, one to Baseline and Fallowfield, the other to Kanata.

Hurdman Station – Ridership east and south of Hurdman follows a similar pattern to Lincoln Fields with rail service to Blair and Transitway service south to South Keys.

Gatineau Traffic – Primarily related to the proposed STO Rapibus service and the interprovincial transfers between Gatineau and downtown Ottawa, the additional predicted ridership numbers push the capacity requirement to 20,000 pphpd, which will determine the overall capacity of the system.

The prediction of this additional capacity should be considered that Rapibus ridership would be approaching the current downtown Transitway volumes. Analysis of the bridge crossings would need to be done to confirm that this level of service is possible. Use of a reconfigures Prince of Wales Bridge, to connect the Rapibus service to Bayview Station in one option to address the capacity across the river.

The pattern of ridership can be used to define the future network as a series of overlapping services that converge on the downtown area. This is similar to the Transitway routes that operate today, with the 95, 96, 97 and 98 operating on different segments of the Transitway network, but all serving the downtown.

The network can be thought of as multiple routes converging on the core. Those routes are:

- Kanata to Downtown
- Fallowfield to Downtown
- Blair to Downtown
- Bayview/South Keys, either as a separate route or interlined to Downtown
- Gatineau to Downtown, either as a separate Transitway route or an interlined rail route
- Hurdman/South Keys, either as a separate Transitway route or an interlined rail route

Optimising the overall network to provide a highly reliable, quality service at a reasonable capital and operating cost will require balancing the ridership predictions with a realistic operating plan.

3. Requirements of the Network

The Transit System is required to satisfy the needs of the network. The needs can be categorised from four perspectives:

- Operations
 - Service offered and utilisation of assets
 - Annual Ridership
 - Fleet size, or numbers of vehicles operated in maximum service
 - Economics
 - Passenger trips per revenue mile or revenue hour
 - Vehicle operating expenses per revenue mile or revenue hour
- Passenger
 - Availability
 - Service levels (hours, frequency)
 - Accessibility (station locations and intervals)
 - Reliability
 - Convenience
 - Travel Times
 - Passenger Loading
 - Amenities
 - Safety

- Vehicle
 - Capacity of vehicle and the System
 - Average speed and delays

- Capital Cost; the cost of the Transit System must satisfy a cost benefit analysis and any other cost constraints defined for the project.

In order to satisfy the needs, a balance must be achieved between these categories. This will mean identifying the key performance criteria and selecting various elements to achieve the best in all categories.

The needs can be satisfied as a part of an overall System design to varying degrees by several forms of transit technology including:

- LRT; examples include the Houston LRT, Minneapolis LRT or Calgary C-Train, typically manually operated.

- Light-metro, typically automated, including Vancouver’s SkyTrain or Canada Line, with other Asian and European examples.

- Metro; mainly semi-automated, with fully automated examples

The application of a Streetcar for the core network can be immediately discounted since it would not meet the capacity needs for an Ottawa Rapid Transit System. A monorail can also be discounted for several reasons, but principally since the operating costs are prohibitive for the level of service delivered.

Each technology will have its strengths and weaknesses, and in order to select the most appropriate transit technology for the Ottawa DOTT, in accordance with the categories above the key performance criteria receiving examination are shown in the following table. The questions must be asked, “What are the key factors to satisfy the requirements?” and “What is then the best system design to meet the overall requirements?”

Category	Criteria	Technology Evaluation	Key Factors
Operations	Service offered and asset utilisation		
	Ridership	Specific targets for peak hours, and the ridership volumes by link	<ul style="list-style-type: none"> • Train capacity • Headways • Degree of segregation • Level of automation • Transfers
	Fleet Size	Which technology offers best fleet utilisation	<ul style="list-style-type: none"> • Train capacity • Level of automation
	Economics	Which technology has been demonstrated in similar conditions to offer lowest	<ul style="list-style-type: none"> • Train capacity • Level of automation • The reliability of each

Category	Criteria	Technology Evaluation	Key Factors
		operating cost	technology <ul style="list-style-type: none"> • Deadheading
Passenger	Availability		
	Service levels	Ability to offer varying levels of service, with short headways in peak periods, and the ability to accommodate fluctuations in demand (e.g. in peak hour)	<ul style="list-style-type: none"> • Train capacity • Headways • Level of automation
	Accessibility	Station locations and intervals must be designed to meet passenger needs regardless of technology	Differences in station and necessary infrastructure costs for different technologies
	Reliability	The ability to guarantee high service levels regardless of environmental conditions or equipment failures	<ul style="list-style-type: none"> • The reliability of each technology • Failure modes specific to the technology • Level of redundancy offered • Tolerance to failure modes • Intervention required to restore service • Degree of segregation
	Convenience		
	Travel Times	Low end to end travel times attract ridership and also reduce the numbers of vehicles required to meet capacity	<ul style="list-style-type: none"> • Degree of segregation • Headways • Level of automation • Transfers
	Passenger Loading	Passengers must have adequate seating and standing capacity with service flexibility to ensure any overcrowding is limited	<ul style="list-style-type: none"> • Train capacity • Headways • Level of automation
	Amenities	It can be assumed that with any technology the passengers will be provided with adequate amenities, however additional amenities may be considered where transfers are required, or where wait times or journey times are prolonged	<ul style="list-style-type: none"> • Headways • Transfers
	Safety	The level of safety and	<ul style="list-style-type: none"> • Degree of segregation

Category	Criteria	Technology Evaluation	Key Factors
		security offered by the various technologies to patrons, operating and support staff, and the System itself	<ul style="list-style-type: none"> • Level of automation
Vehicle	Capacity of the vehicle and the System	The capacity of the vehicles and the system to meet the various ridership demands while providing a high level of service	<ul style="list-style-type: none"> • Train capacity • Headways • Level of automation
	Average speed and delays	Which technology can offer highest average speed with least amount of delay to passengers	<ul style="list-style-type: none"> • Degree of segregation • Headways • Level of automation • Transfers
Capital Cost		How does the choice in technology solution in meeting the needs affect the overall capital cost of the	<ul style="list-style-type: none"> • Vehicle capacity • Fleet size • Degree of segregation • Level of automation

The following sections present a further overview of some of the key criteria and key factors to be examined as a part of the technology assessment.

3.1 Capacity

3.1.1 Definitions and Assumptions

The capacity or '*Person capacity*' is the maximum number of people that can be carried in one direction over a section of track in one hour, under normal operating conditions. Capacity is measured in pphpd or passengers per hour per direction.

For the purposes of comparison we have assumed that the track is ideal and there are few network delays.

3.1.2 Core Network Capacity

Figure 6 is similar to Figure 5 shown in the previous section. The capacities that can be provided using different vehicle technologies are shown against the predicted ridership.

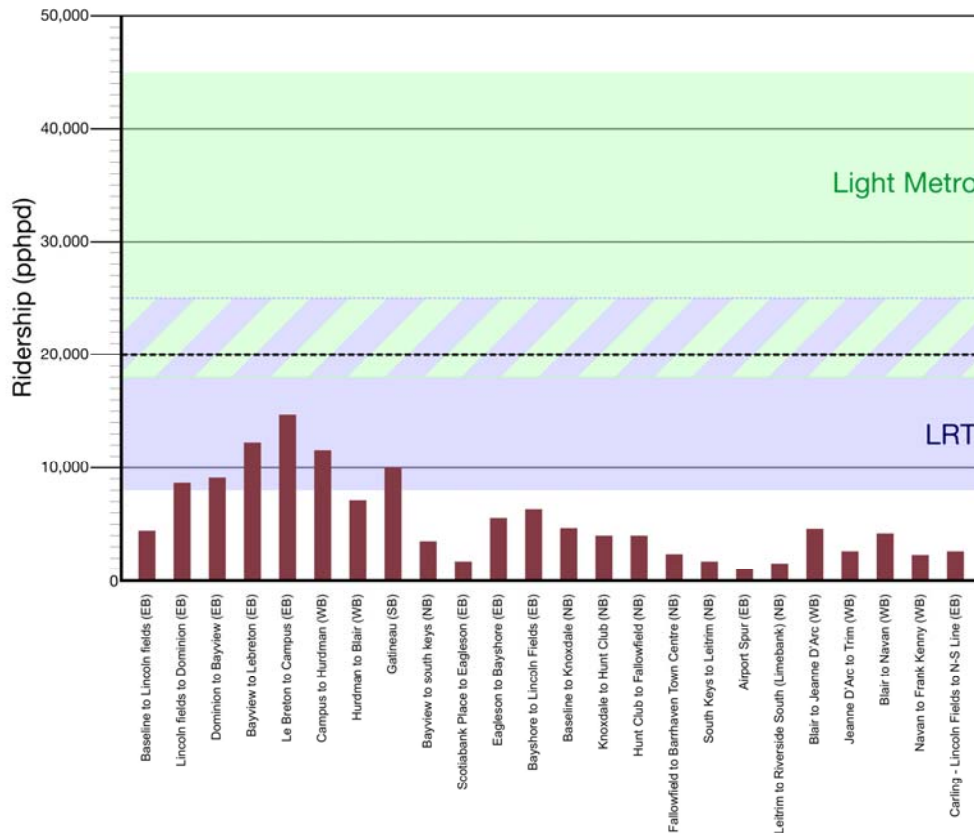


Figure 6 - Core Network Capacity

The figures below highlight the differences between two operating scenarios within the main core.

- Figure 7 has a single route operates from Baseline to Blair, with the size and frequency of trains matched to the peak load along the route. A maximum load of 16,000 is needed for the peak hour to carry the predicted 14,400 passengers, with some spare capacity for busy days and short-duration peaks within the peak. The corridor from Bayview to South Keys is assumed to be a separate technology or service as low demand does not warrant high capacity vehicles.
- Figure 8 has three distinct services, with different start and end points, operating simultaneously. Each service is capable of carrying 6,000 passengers per hour, and together can carry 18,000 pphpd through the central segment from LeBreton to Campus.

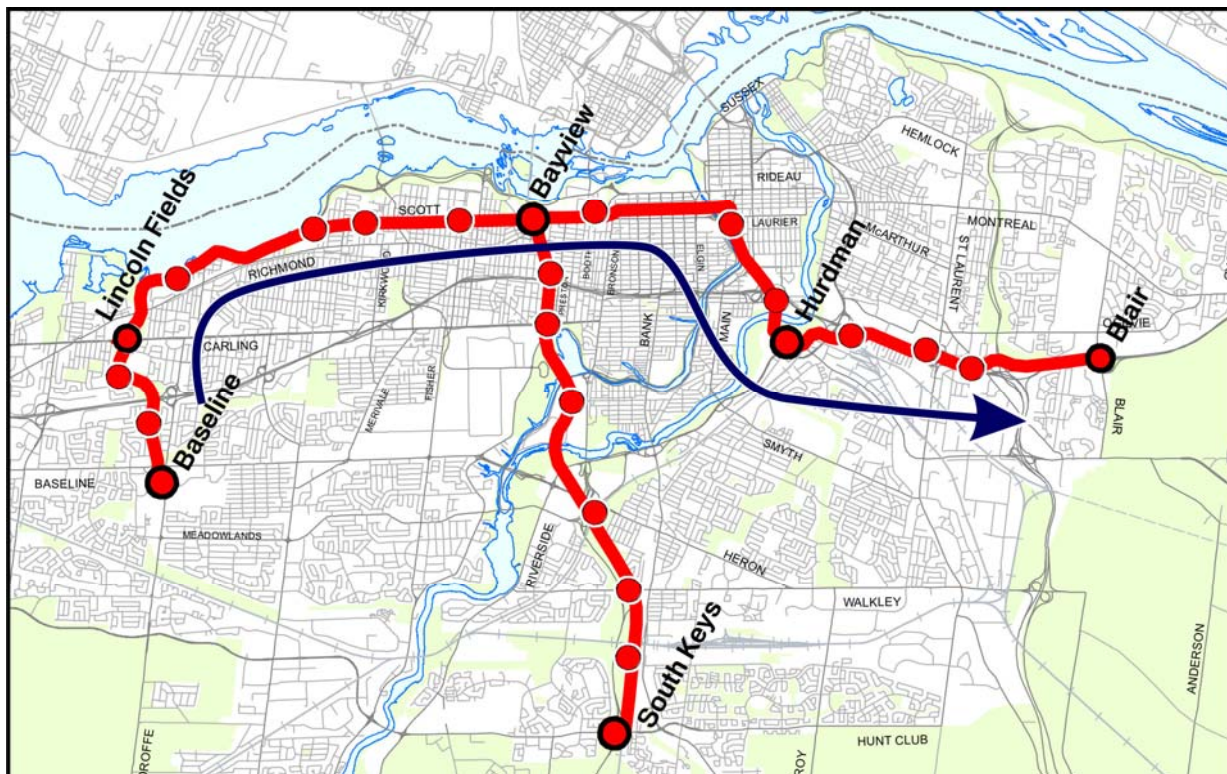


Figure 7 - Single High Capacity Route

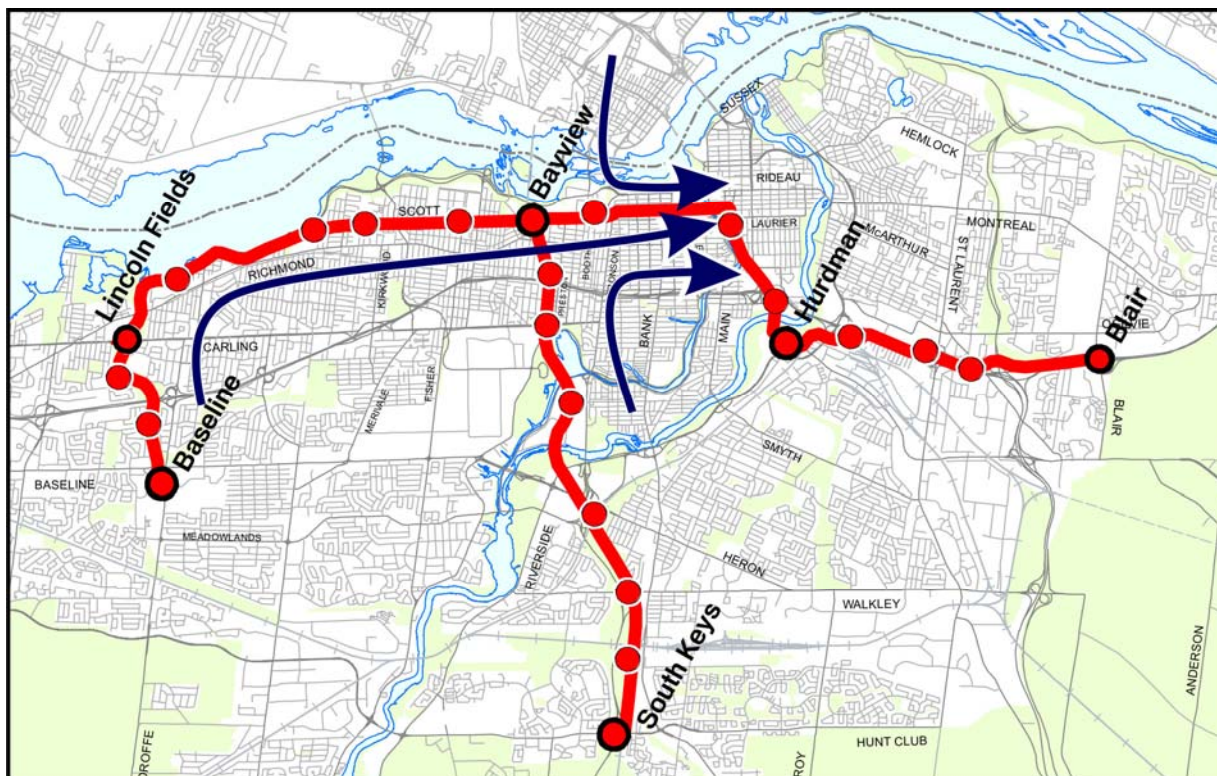


Figure 8 - Triple Service Route

While both of these operating scenarios carry the same number of people out of the downtown they achieve the result in very different ways:

- In the first scenario (Figure 7);
 - Passengers can board any train that arrives at any of the downtown stations
 - Connections to services at the suburban end will require a transfer
 - The same total capacity is operated at each of the stations regardless of demand, resulting in a significant number of empty seat-kms.
- In the second scenario (Figure 8);
 - Passengers need to select the specific train they want (unless they are only travelling a few stops, in which case they may have more than one choice)
 - The service can be extended further without the penalty of empty seat-kms
 - The capacity is matched to demand but is a more complex system to operate and for passengers to understand
 - The complexity is higher and delays on one branch of the service can have an impact on other branches
 - The number of seat-kms offered in the downtown needs to be slightly higher as passengers will choose to wait for their desired train, leaving more space empty on each train.

These two scenarios will be explored in more detail below, but form the base problem that the selected technology will need to address.

3.1.3 Train Capacity

Capacity is defined as the number of passengers per hour per direction that are carried on a system, and is defined by the number of individual cars in each train, the standing room and the number of trains per hour that are operated. To derive the total capacity of the system we need to look at the capacity of each train, and of the cars that make up each train.

While a train may be made up of several cars, it is the capacity of each car that is the determining factor. The capacity of a car is defined by the seating capacity and the use of the suitable remaining floor space for standees. Various loading standards are used to define how many standees are on-board a train, and the standard used for planning the system can vary by time of day. The industry standard loadings are:

- AW0 – Empty vehicle weight
- AW1 – Seated Load, including the driver
- AW2 – Seated Load plus 4 passenger per square metre of suitable standing space
- AW3 – Seated Load plus 6 passengers per square metre of suitable standing space (often termed the crush load)

Many cities use the AW1 standard for early morning and late evening service, AW2 for shoulder peak periods and the midday and AW3 for peak hours in the core portions of the network. Ottawa and other North American cities have set a target of a seated load plus 2.5 passengers per square metre for the peak hour service level for service planning.

3.1.4 Operating Capacity

The ridership capacity on any segment of the network is theoretically calculated as the number of passengers per train multiplied by the number of trains per hour. Longer, less frequent trains and shorter more frequent trains can yield the same total operating capacity, for instance;

- 6-car trains operating on 6-minute headways = 60 cars per hour
- 3-car trains operating on 3-minute headways = 60 cars per hour
- 1-car trains operating on 1-minute headways = 60 cars per hour

These three different combinations provide the same total capacity, but operate in very different fashions. Operating a train every minute is difficult to achieve, even with modern train control technology. For most systems, the practical lower limit on headway is 1.5 minutes (90 seconds) and by using some flexibility in inter-station run times this allows some margin to improve speed, resulting in the resolution of system perturbations over a period of time. The Automatic Train Supervision (ATS) component of the ATC is now very effective at resolving junction management issues, bunching etc.

In some scenarios, it may be necessary to delay all trains by half a headway or so to restore system equilibrium and gives credence for the need of additional capacity in the trains.

One objective of any transit system is to closely match the expected ridership of the line with a predefined number of cars which can, with comfort and safety, contain the passengers. The operator has to continually marry the demands of the network and balance operational costs by minimising the

number of cars on the track throughout the day. As a result an operator may operate five or six trains at peak times and only two or three trains in off peak times to optimise running costs of the network.

3.1.5 Historical Capacity Predictions

Historically a number of LRT systems have under predicted ridership due to poor interpretation of the positive ridership response to rail transit. To mitigate the effect of under prediction the station platforms and power supply system will be designed to allow enhancements of the network by adding additional vehicles should ridership increase beyond projections.

3.2 Travel Times

Travel times are a key determinant in the success or failure of a transit system. The actual time taken for the complete journey, including potential wait time (impacted by headway, or service interval) and the number of transfers between transit modes will all have an impact on the modal share (proportion of trips made) by travellers compared to other transit means such as the car or bus.

In general, for a person travelling from home to work there will be many factors involved in the overall travel time. In consideration of the transit network only, the elements of the travel time calculations for the journey will include:

- The accessibility of the transit station(s) for pedestrian access, including walking distance to platform from other forms of transit (park and ride, bus, kiss and ride)
- Number of transfers along the journey (change of transit mode such as from bus to train, from LRT to Light-Metro, from line A to line B, etc.)
- The average speed that can be attained for each transit mode or line.

The average speed along a line will be a product, including many factors, including:

- Maximum operating speed (expected to be 80kph based on other North American operations).
- The extent of gradients, which reduce acceleration or deceleration rates, and the numbers and radii of curves, which force speed reduction.
- Distance between stations, where short distances prevent the vehicle from travelling any significant distance at the maximum speed.
- The level of automation (Automatic Train Operation (ATO) which can reduce travel times compared to human operation by significantly by improving speed control and allowing more precise braking, and better station stopping accuracy).
- The length of the platform and the length of the train. A longer train will take a longer time to run-in to the station and stop, thereby adding to the travel time.
- Vehicle loading and performance capability (while a lightly loaded vehicle will be able to accelerate at a greater rate than a heavily loaded vehicle, the propulsion capabilities of the vehicle must also be considered, and this should be considered equal for all vehicle types since the performance capabilities will be specified for the highest loading levels).

The total trip time on a Transit System is a function of the individual inter-station run times and the dwell times. The dwell time is considered to be the interval between doors fully open and doors starting to close. The required dwell time will be a function of:

- The vehicle and platform loading

- a heavily loaded vehicle will take longer to load than an empty vehicle because of the congestion in the interior and at the vehicle doors, and
- a heavily loaded platform will often mean that passengers still boarding at the end of the dwell may obstruct doors from closing, thus causing the recycling of doors and delays.
- The numbers of passengers exiting the vehicle.
- The numbers and width of doors.

In addition to the dwell time there is the dwell overhead. The overhead includes a number of factors:

- The time to open and close the doors. For heavier rail vehicles where doors slide into pockets the door open/close times can be lower than for light rail vehicles where doors are required to fold, and where an accessibility step may need to be extended and retracted.
- The time taken from the point the doors are confirmed closed and locked to the time the vehicle starts to depart.

3.3 Fleet Size

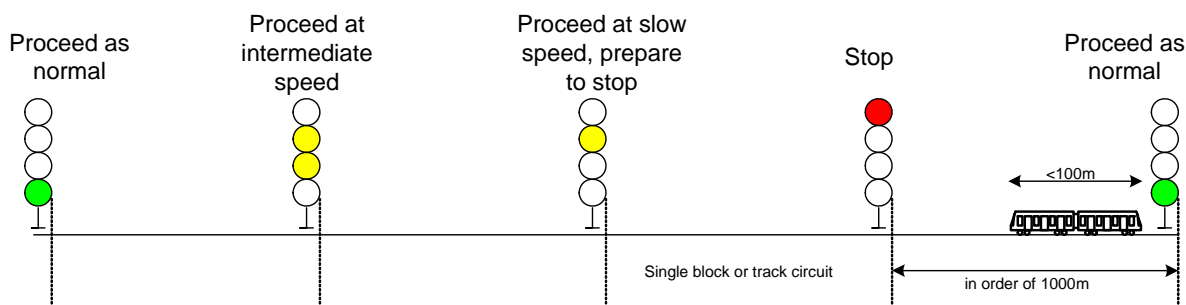
The total Round Trip Time (RTT) is the time taken for a vehicle to travel a complete circuit of the System, and is an important factor in any Transit System. For any given headway or service interval (time between one train and the next) the numbers of trains required to support that level of service is based on the equation:

$$\text{Fleet Size} = \text{RTT} / \text{Headway}$$

For example, with a RTT of 60 minutes and headway of 3 minutes, a fleet size of 20 trains is required. If the RTT can be reduced by 3 minutes, then one train can be eliminated to provide the same capacity, where the overall capacity is based on the capacity of the train, and the number of trains passing through a given point in an hour. So the capacity does not change but the fleet size can be reduced and the passengers benefit from reduced travel times.

3.4 Levels and Impacts of Automation

Railway signalling has conventionally used track-circuits with trackside signals, where the signals provide an indication of how far ahead a train can proceed, and the approach speed before it encounters a track section or block of track that is occupied. This is called fixed block signalling with signals provided at the approach to each block as shown in the following figure.



In order to better utilise track and improve capacity and travel times, trackside signals may be replaced with a signalling system located inside the cab, this is known as in-cab, or cab signalling

(CABS). Again track circuits are largely used to detect a train's presence, but are also encoded to provide the train with a speed code limiting the train to a safe speed depending on distance to the next train or obstacle, or track limitations (speed restrictions). Updates or changes in condition can be provided immediately and so the driver does not have to wait until he arrives at the next signal. A typical cab display is shown in the following figure.



Figure 9 - Typical Cab Display

As an alternative to track-circuits, communication based train control (CBTC) was developed and has been in service providing automatic train control since the 1980's. CBTC provides continuous communication between the train and the track equipment, it allows fixed block track circuits to be replaced with a protection zone or block established around the moving train, hence the term 'moving block' as opposed to the fixed blocks provided by track circuits. The onboard train control is able to calculate the vehicle's position based on the measured distance travelled between trackside markers, and relays the position through the communication system to the trackside train control equipment. Knowing the speed and location of all trains in the system, the system can then safely regulate the speed of any train on the network to avoid collisions. CBTC allows fixed block track circuits to be replaced and create a protection zone or block around the moving train, hence the term 'moving block technology'.

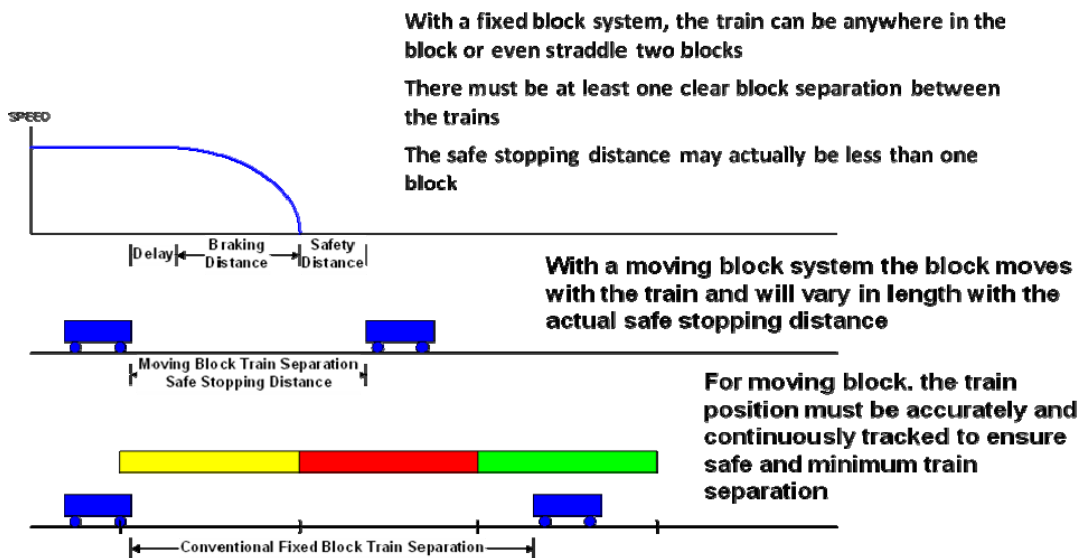


Figure 10 – Fixed Block versus Moving Block Signalling

While many advances have been made in technology and signalling, many rail vehicles share their right of way with road vehicles, and operate in manual mode obeying line-of-sight rules. This provides the driver with complete control over the vehicle, much the same as any road user, except that the vehicle direction is guided by the rails and track switches. This is sometimes supplemented by an over speed protection system that will automatically brake the vehicle should the driver relinquish control or the vehicle goes over the set speed limit.

The levels of train control that can be implemented are therefore as follows (Highest order first):

ATC – Automatic Train Control (Automated operation)		Method of Signalling	Examples
UTO	Unattended Train Operation, with vehicles completely unattended, although there may be roving attendants	CBTC and Moving Block	Automated light metros and metros; Vancouver SkyTrain, Paris Météor, Singapore Metro
DTO	Driverless Train Operation; no driver, but there is an attendant for failure management or customer care	CBTC and Moving Block	London Docklands Light Rail (DLR)
STO	Semi-automatic Train Operation; driver, functions may be as limited as closing doors prior to automatic station departure, also general failure management.	CBTC and Moving Block Track Circuits and Fixed Block	Metro systems Scarborough Rapid Transit
SIGNALLING – Driver operation or Manual Modes			

ATC – Automatic Train Control (Automated operation)		Method of Signalling	Examples
CABS	In-Cab signalling providing indication to the driver of commanded speed or distance-to-go, usually enforced by ATP.	Track Circuits and Fixed Block	Commuter / Regional Rail
Track side (Wayside)	Line of sight driving with line side signals. Includes limited ATP such as automatic train stop in case a signal is passed at danger.	Track Circuits and Fixed Block	Commuter / Regional Rail / Freight
Line of Sight	Line of sight driving with no line side signals, may be provided with overspeed protection	None	Street cars

While ATC has been implemented using track circuits with UTO capability, the application has been limited to automated people movers (APM), with much lower capacities or limited operations. ATC includes three components that may be implemented to various degrees depending on the operational requirements and level of automation required:

- Automatic Train Protection (ATP): Implementing safety functions for collision avoidance etc.
- Automatic Train Operation (ATO): Essentially drives the train according to a schedule or performance targets (speed, braking).
- Automatic Train Supervision (ATS): Provides and modifies the system schedule and performance (route, headway, dwell time, schedule) information to the whole fleet or a group of vehicles.

The application of higher levels of automation unquestionably improves travel time, headways and System performance. Manual driving with fixed block in-vehicle cab signalling (CABS) provides significant improvement on performance levels compared to Manual driving with fixed block track side signals, however Automatic train control, using moving block signalling, provided by CBTC provides the highest performance levels.

An important factor in the travel time is the degree of segregation of the right of way (RoW). Where the RoW is completely segregated from other transit vehicle and pedestrian traffic far greater speeds can be attained. If the rail vehicle shares a transit corridor with road vehicles, with at-grade crossings at road intersections then a much lower speed is possible. Some onboard automatic train protection (ATP) will be provided, but this will be limited to over speed protection. CBTC can be added to allow determination of the vehicle's location, and also in-cab signalling (providing speed targets and distance to go information to the driver).

Typical non-segregated LRTs operating in dedicated lanes operate at average speed of around 25 kph, depending on the distance between stops (stations) and the numbers of intersections, whereas with segregation average speeds of 35 kph are common.

At the core of the network, in the tunnel area and other segregated segments of the system, if the same level of automation is applied the inter-station run times and dwell times should largely be the same, with minor differences between technologies based for example on the differences in dwell

overheads, however for any segments that are not segregated and operate with street running then the average speed will be significantly decreased, thereby increasing passenger travel times and increasing the fleet size necessary to deliver the required capacity.

3.5 Flexibility and Resilience

Higher levels of automation with continuous communication between each vehicle and central control provided by CBTC, also allows real time modification of system performance to respond to failure modes or fluctuations in service demands. For example in the event that a significant delay has accumulated and has caused much of the fleet to bunch up, through central control, and Automatic Train Supervision (ATS), the schedule can be adjusted so that all trains reduce speed in the system, or pause with increased dwell at stations to restore equilibrium and a more even separation. Conversely trains can simultaneously be commanded to increase maximum speeds and acceleration/deceleration rates within safety and comfort levels to increase the line capacity.

In the event of a surge in demand, again the whole fleet can be assigned to a higher performance level (increased speed, acceleration and brake rates) with reduced headways to add capacity to the System, and furthermore additional trains can be readily added when the system is UTO because it is not necessary for additional operators to board the vehicle.

3.6 Headway

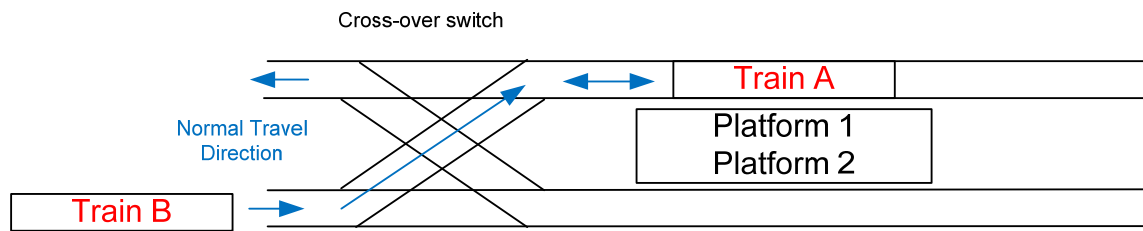
The headway at any point in the System is calculated as the time between two following trains at that point. The minimum headway that can be set is a product of several factors:

- Minimum safe train separation distance, based on the train control system's knowledge of each train's location. This will be at the minimum for a moving block train control system, and the maximum for a fixed block signalling system where a vehicle can be assumed to be anywhere within a relatively large block.
- The dwell time (including overhead) at the maximum load point station (typically busiest downtown station or terminal station).
- The operating margin (required to allow a train that has been delayed some make-up time).

3.6.1 Terminal Station Design and Impacts on Headway

Terminal station arrangements can severely limit the headway. With manual train operations, sufficient time has to be allowed for the driver to change ends, or an additional driver should be waiting at the correct position (known as step-back operation), or a spare train is required on the opposite platform. The spare train would be an addition to the number calculated by the fleet equation [Vehicle Number = RTT / Headway].

With automation, there is no additional driver delay. The terminal station layout is also important and a typical layout is provided below with a double cross-over at the front of the station for operational flexibility and failure management. The centre island platform allows passengers to board at either platform.



In this example if Train A is occupying the normal arrival and departure Platform 1, then in order to avoid delays to Train B, Train B can be diverted to Platform 2. Once Train A has departed and cleared the switch zone, Train B can depart and switch back to the normal travel direction.

In Toronto, the trains alternate platforms during peak operation, where:

- Train A is on Platform 1,
- Train B arrives and goes straight into Platform 2,
- Train A departs straight out,
- Train C arrives and crosses over to Platform 1,
- Train B departs across the switches,
- Train D arrives and goes straight into Platform 2.

This pattern is repeated throughout the peak period, and may be used during the midday and evening periods in some instances. This method requires an additional train to be held at each terminal station, with a short overlap between one train arriving and the previous departing to maintain short headways.

Automatic Train Control provides the alternate berthing functions only as required and pre-positions the track switches to improve operating efficiency so that each train can operate on a short dwell with no spare trains required.

3.6.2 Impact of Train Length on Headway

The practical limit for headways varies by train control technology and also train length. Increasing the train length increases the effective block length, but has less of an impact on the minimum headway with a CBTC based moving block technology than it does with either CABS or trackside signalling using fixed block.

3.6.3 Headway Limitations

Typically for CBTC based moving block technology, a system will have a theoretical limit of around 60 second headway, and for manual signalling or CABS signalling the theoretical limit would be around 80 seconds.

Taking terminal stations and other factors into consideration, a more practical limit for CABS or trackside signalled systems is 120 seconds, whereas with Moving Block the current practical limit is 80 or 90 seconds.

3.6.4 Segregation Choice and Impacts on Headway

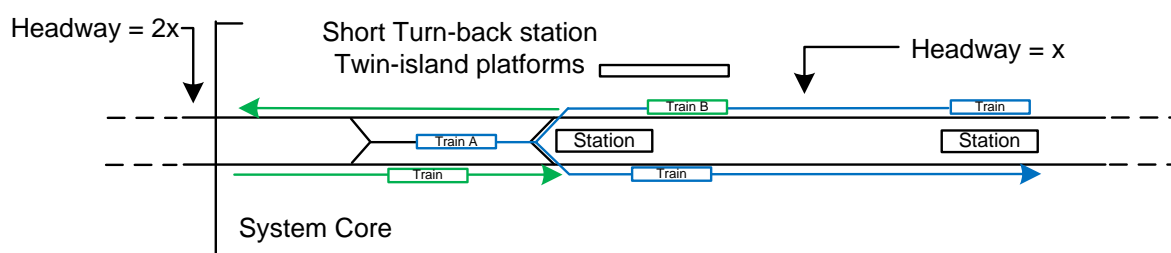
Where vehicles are operating in non-segregated, though dedicated lanes, with grade crossings at intersections, the headway is typically limited as a minimum to twice the intersection signal cycle time, so that if the traffic signal cycle is 2 minutes, the headway cannot not effectively be less than 4 minutes. To ensure optimum travel time, and in the case of delays, Traffic Signal Priority (TSP) is provided to the transit vehicle. However, sufficient signal time still has to be provided for normal right turn and traffic movements both across and through the intersection. In some cases to ensure transit capacity is maintained and to avoid road traffic failure grade separation at the intersection may have to be considered.

Where segregation is not provided, line of sight manual operation may be supported with CABS indication of vehicle location and distance to go, and with overspeed protection, however the headway will be further limited as described above by other considerations such as at-grade road crossings.

It is possible however to operate with a combination of manual (with CABS) and automatic operation in different segments of the system, and this is now being done in some LRT and Light Metro systems.

A higher level of automated service is provided in a segregated core (e.g. tunnel) by allowing short-turn back operation, of every second train to service the higher demand stations. The turn-back is implemented using track switches and requires automatic train control to ensure efficient implementation.

In the following figure the turn-back station includes a pocket track to the rear, Train A berths at the station and is then switched out of the primary track to the short turn-back pocket track so that it doesn't cause a delay to the following Train B. Train A is then inserted back into the core operation in the opposite direction. The short turn-back arrangement as a result is more complex with increased costs.



As a result of the turn-back the headway outside the core is effectively double that inside the core, so it is conceivable that 2 minute headways can be achieved inside the core and 4 minute headways outside. Once trains have left the core they switch to manual (CABS) operation. This can however causes problems:

- Those passengers who wish to leave the core will have to wait for every second train, this can cause overcrowding on those trains and extend the dwell times, causing delays.
- When a manually driven vehicle is driven into the core it switches at a transition zone to automatic operation, and slots in between two short-turn-back trains, however if it is not on schedule, and has already accumulated some delay, it can cause or exacerbate further delays to the down-town, or core operations.

This interleaving of services at a turn-back station, or junction is more effectively implemented with full segregation, allowing full automation throughout, and the use of proven junction management functions implemented by the automatic train control.

Thus short headways can best be realised with the use of Communication Based Train Control (CBTC) offering full automation and moving block signalling.

3.7 Deadheading

Travel times also have an impact on Deadheading. Deadheading is the term used to describe the trip made by the rail vehicle without transit passengers. Deadheading therefore occurs at the start of service when vehicles are pre-positioned in the System to begin revenue operations. However deadheading also occurs at transitions between service levels, i.e. at the end of the am peak period when vehicles are removed from service, or prior to the start of the pm peak period when additional vehicles are inserted into service.

Deadheading requirements can significantly reduce the available window for overnight track work. After the last train goes out of service at the far end of the line, it must return to the yard, and before service begins in the morning, trains must be positioned for service start-up. If the last train ends service at 1:00 AM, and service restarts at 6:00 AM, the theoretical 5 hour maintenance window is reduced by the two deadhead times. Without proper planning, some cities have experienced maintenance windows as short as 45 minutes immediately adjacent to the Maintenance Yard connections.

A rail transit system with higher levels of automation and full segregation of the RoW can be expected to control and reduce the impact of all of the factors associated with travel time, dwell time and dwell overhead.

3.8 Reliability of Service

The reliability of service is a key consideration for any Transit System, and both reliability and availability targets are generally set to ensure that a level of service will remain available, even with failures, for a specified percentage of service hours. However definitions of availability, or specifically what is represented by “unavailable”, vary greatly from System to System.

A common measure of unavailability is a train delay anywhere on the System, of more than two headways. Of course the headway may vary significantly during the day, but so does the impact of a delay, with more passengers affected during peak periods than during off-peak periods. The operating company or owner must therefore set a meaningful target in terms of an average acceptable time between system failures that would cause a delay of more than two headways. This is known as the mean time between service affecting failures (MTBSAF).

Some Transit Authorities also include other measures of availability, for example by including a measure of on-time performance, where a % of trains must arrive at each station on time (allowing for a certain margin of error). But where train frequency is in any case of the order of 2 to 5 minutes this measure ceases to be relevant, and it is often difficult to assign the cause of the delay to the System where other factors (mainly passengers) are involved.

Other factors may also be included in the availability measurement such as maintenance levels, spares utilisation and spares holding, train and station cleanliness, availability for service of spare fleet etc.

These measures are often included in performance measures where a system provider not only delivers a Transit System, but also then operates and maintains that System.

In order to set the target availability the system configuration must be well defined. For example, the larger the in-service fleet, and the smaller the train configuration (number of cars) the more likely the possibility of a service affecting failure.

Consideration should therefore be given to which train technologies can best meet the need for high availability by offering a combination of:

- Proven in service, with low risk of failures due to maturity of technology in the application.
- The most reliable equipment, or lowest failure rates, in any of the environmental conditions encountered.
- The highest tolerance to failures (e.g. through redundancy), and
- The ability to reconfigure in response to failure modes.

3.9 Service Proven

Problems often occur where new and un-service proven technologies are applied before all the bugs are removed and the technology and its use in the intended application are stable. Often the problems are software related and may not manifest themselves until some unforeseen combination of operational, environmental or failure conditions occur. Service proven aspects of any technology are therefore important.

There is another aspect of service proven and that relates to all of the proposed system technologies have been proven as an integrated system. For example, even where two technologies may be considered to be service proven on their own they may never have been integrated for use in a particular application. For instance CBTC and UTO have been implemented with light metro, but not yet with a low floor LRT platform. This may necessitate some redesign of the vehicles to integrate propulsion, braking and train control functionality to more closely match their light-metro counterparts that have been service proven with this technology.

In the event that the uniqueness of a particular set of transportation requirements necessitates a combination of system technologies, e.g. CBTC with Low Floor LRVs, it is critical to recognise the need for additional system integration activities. This will require an extra investment in design reviews, test planning, integration testing and commissioning. With upfront planning of appropriate risk mitigation measures, the systems integration risks can be satisfactorily addressed.

3.10 Reliability

For the two transit technology choices under consideration, all use very similar components, from door operators, to brake systems, and so equipment reliability itself is not usually a concern.

If reliability requirements cannot be addressed by the elimination of possible failures, it can often be addressed through redundancy. Higher levels of technology, for example using Automatic Train Control, usually also offer higher levels of redundancy thereby providing a higher degree of tolerance to failure, than more manual counterparts.

However some applications of technology may influence additional failure modes. For example, a fully segregated right of way ensures that there can be no impact on service from external influences. By comparison a transit system using a dedicated transit corridor along the median of a roadway may encounter at grade road intersections. The possibilities always exist at these locations for road vehicle collisions in the intersections, or for other types of delay caused by human interaction or equipment failure.

3.11 Failure Management

A high level of availability does not mean that equipment cannot fail, but it does mean that failures should be tolerated without an unacceptable impact to operations. Therefore it might be possible for an operator to reset or restart equipment, or switch over a function from the failed equipment to a back-up unit and restore operations, before a delay of more than two headways is accumulated.

In heavily automated systems, service is usually restored by the automatic, or remote switch over (from central control) to back-up equipment, or by the rerouting of service through alternative switches etc. Therefore both high levels of redundancy and reliability are required. For a train consisting of several vehicles redundancy is naturally provided for most failure modes. The system design should support for example the failure of one out of several traction motors, without delays to service. The failure of a single door to open should also not lead to a delay in service of more than two headways. In both cases however the response might be to remove the vehicle from service at the next opportunity.

Most Transit Systems are also usually controlled and monitored from a central control location, from where failure management strategies, including passenger communications can quickly be deployed. Automated Transit Systems usually provide more capability for remote failure management and restoration of service through remote intervention since vehicle operators and even station attendants may not be available to manage events. By comparison if operations and maintenance staff were instead required to be dispatched to the field it would not be possible to resume service within the necessary time period.

In spite of the often higher reliability, and failure management capabilities unmanned systems do of course lack onboard personnel who can sometimes be useful in failure or security management situations, either to reset faulty equipment, operate a vehicle at a lower level of service, or else communicate with or assist passengers directly. To offset this in highly automated systems, roving attendants are often employed to move throughout the system. The attendants who can then be quickly made available to assist passengers or take failure management action as required.

3.12 Segregation

3.12.1 Types of Segregation

The segregation of the corridors can be grouped into three types:

Non Segregated (At Grade or street running)

At-grade is the cheapest method, but cannot accommodate demand or higher-order technologies and necessitates the use of a driver to provide mitigation against unplanned events or safety risks.

Partially Segregated

A partially segregated right of way provides a lower cost alternative, with better community integration but generally cannot accommodate the predicted demand or higher-order technologies without significant mitigation of safety risks.

Examples of partially segregated areas are:

- Raised median, where the track bed is raised by approximately 5cm from the adjacent traffic lanes to provide simple separation
- Fenced areas, where the tracks run beside a roadway and are enclosed with fencing
- Reserved lanes, where a vehicle shares the highway but is separated either side by a low level curb or paved area to allow pedestrian crossing and provide a definition for the corridor.
- At-grade street crossings, where the tracks run beside or down the median of a roadway, but cross perpendicular streets at grade, requiring integration between the LRT signalling systems and the traffic lights to protect the crossing.

Fully Segregated

A fully segregated right of way is the most expensive solution but can accommodate more demand and higher-order technologies but may suffer from integration issues. Depending on the method of segregation a fully segregated right of way will often allow integration into an urban environment without impacts to other users of the transit corridor. For example an elevated guideway may be built along a road or highway median without impacting the capacity of the existing corridor and can be built while maintaining a significant portion of the transit corridors capacity, thereby having less of an impact.

Fully segregated corridors can take three forms:

- Above-grade or Elevated, such as the majority of Vancouver's SkyTrain,
- Below-grade in a Tunnel, Cut-and-cover box or Trench, such as Montréal's Metro, and
- At-grade or Fenced, such as portions of Toronto's subway near the suburban ends of the line.

3.12.2 Costs of Segregation

The requirement to control the land, provide for local road crossings, to excavate and construct the system below grade or to build elevated guideway are the major costs of segregation. In addition to the costs to construct the actual system are related costs to relocate utilities (both temporary and permanent relocations). Even the costs to implement a limited number of local road grade separations can be very expensive.

Fortunately, the main core segregation costs have already been largely accommodated by the existing Transitway, although there are some minor alterations required for adaptation to a new form of transit mode. The construction of the proposed new tunnel will remove the largest segment of the system that is not currently segregated.

The costs of segregation are therefore most important beyond Lincoln Fields and Bayview, but also the minimisation of the impact on visual, aesthetic and environmental aspects of the Greenbelt areas into the outlying areas of the city.

To minimise the cost of segregation and therefore minimise capital cost, the transportation corridor choice should provide for the minimum segregation required while not compromising public safety or affecting operating schedule. It is therefore always preferable to ensure that the corridor choice can accommodate a range of vehicle operating modes. In the main core the corridor is fully segregated and we can take advantage of automated operation to provide a more efficient and less costly system. However the choice of an automated system in the core will dictate that any developments outside of the main core will incur significant infrastructure costs from the outset of construction.

Therefore the technology choice requires to be able to provide the transit system designer the largest possible choices of operation from driver operation to automation while keeping system infrastructure costs low for the short term and once the ridership revenue starts to accumulate look at how the system can be upgraded to meet the demand and scheduling needs.

The flexibility of driver operated /assisted vehicle that can also operate automatically allows more cost effective short term solutions for infrastructure and minimises initial capital expenditure and will match the early ridership predictions in terms of potential revenue. Also another benefit is that the vehicles can be driven in driver operation mode in the event of automated system failure or when repair and maintenance/upgrade of the automated system is required.

3.12.3 Key Segregation Costs

The key future segregation costs for the main core (outside of the downtown tunnel) are related to grade-separation at Iris Street, and the route between Dominion and Lincoln fields. For similar vehicle weight and capacity and where Light Metro and LRT both use overhead catenary the costs will be comparable. However cost differences between Light Metro and LRT can arise from the segregation and protection of the public from exposed components of the power system.

Where underlying geology and water tables prevent normal cut and cover tunnelling, embankments will require construction resulting in grade changes, impacting affecting visual appeal and potentially blocking pedestrian access, which may result in with the construction of additional walkways. Low cost segregation can be achieved by the closure of roads crossing the alignment; but this may impact existing traffic circulation and levels of service.

Outside of the main core the large expanse of Greenbelt crossing necessitates a low cost corridor choice to minimise operational costs. However the visual impact, ease of land acquisition and the effects on wildlife may require more expensive alternative fully-segregated designs. This may be significant at existing at-grade intersections, where for driver operation only signal controlled crossing are required, whereas a fully segregated line would require either cut and cover tunnels or elevated sections.

As a result of the structures required for grade changes necessary for the segregation of Heavy rail crossings, the outlying communities in the North-South and South-west will also incur additional costs.

The corridor between Carling - Lincoln Fields is largely determined by technology choice; in the event of the construction of a Light Metro system the corridor would require grade separation or an elevated guideway to be constructed for a short segment of track. If the cost of segregation is too prohibitive, the vehicle technology choice may be likely to be LRT- based to meet the projected ridership; this will entail further transfers at both ends of the corridor and an isolated corridor surrounded by Light

Metro. The Carling corridor, if it were to be Light Metro would need to be fully segregated and the cost could be prohibitive.

3.12.4 Beyond 2031

The cost of segregation becomes more important beyond 2031 as potential expansion of the rail network beyond the inner urban area is considered. As outlined in the TMP, expansion to the outer urban communities of Kanata, Orleans and Barrhaven is dependent on density targets being met within those communities. This is not expected to occur within the horizon year of the existing TMP. However, just as long-term ridership demand is informing technology decisions made for the core network, consideration should also be given to the implications which any future expansion across the Greenbelt would have on technology decisions.

Based on projected ridership demand, the cost of providing fully-segregated rapid transit corridors beyond the core network is considered to be high, as demand on all corridors is well within the capabilities of a partially-segregated rapid transit corridor and will likely remain so far into the future.

With respect to crossing the Greenbelt, special consideration needs to be given to the impact which technology decisions will have from an aesthetic and environmental standpoint. Technologies needing a fully-segregated solution would require construction of an elevated or underground alignment across the Greenbelt, unless an at-grade corridor, which effectively cuts off all perpendicular access, was permitted.

Once across the Greenbelt, integration of the rapid transit corridors into adjacent communities will be made more difficult should a technology needing full segregation be selected. For instance, the Riverside South community has been planned and designed to accommodate LRT technology running in a partially segregated right-of-way, with at-grade intersections.

A technology which can provide safe operation in both partial and fully-segregated corridors will be advantageous to provide a staged implementation of rail rapid transit in the future.

3.13 Transfers

A key area for consideration is the effect of transfers on the network performance. This is more prevalent at Bayview station as it forms a major hub and potential transfer point for East-West and North South traffic.

The assumption is that the E-W line will have some form of automation to capitalise on segregation, while the N-S line will either be driver operated/assisted or have partial automated running for a portion of the line.

Currently there are two options for this station.

Transfer station – Where passengers will be required to disembark from their current train and wait for a connection.

This is the easier option to implement and requires passengers to transfer for their onward journey. This also breaks the journey and requires passengers to complete their morning train based activities in advance and can be perceived as a disadvantage. The vehicle can be turned back on a return

journey without affecting the main core schedule. This provides two distinct networks for optimal system performance at the expense of a transfer for the passenger.

Synchronisation of vehicles can be achieved and regular services on the main core can minimise transfer times; however the transfer time is affected by network delays on either line. Generally when travelling into the core the transfer is from a higher headway to a shorter headway, thus wait times are not as significant as the return journey.

The length of transfer is also important with respect to building ridership, if there is significant delay and inconvenience to the passenger during transfer this tends to not encourage ridership increase and can in fact have a detrimental effect on mode choice. Platform transfers are more ideal as the passenger remains within the transfer station area.

Through station – Where passengers remain on the vehicle and the system inserts the vehicle into the main line. The predicted ridership of 9000 pphpd can be accommodated by a five vehicle consist with a rider capacity of 150 providing a train capacity of 750 riders. The five minute headway means that 12 vehicles are required to operate at peak hour through the main core.

Given that an automated system or Driver assisted system can safely operate at 1.5 minute headways, a five minute headway allows the insertion of one or two smaller capacity trains in to the main core with some margin of time to compensate for any delays associated with possible driver operation on the N-S line.

A disadvantage is that the smaller capacity train moving in the easterly direction in the main core will have a higher loading in peak hour for some stations, but will closely match the capacity requirements and provide better efficiency as the vehicle moves in the easterly direction.

The reverse is true for westbound vehicles; they will require insertion at Hurdman, will run at capacity and optimal efficiency for a large proportion of the tunnel and finally run at a higher capacity at the Downtown west station until Bayview.

Despite this potential requirement for higher capacity, current experience shows that passengers will delay their onward travel in the main core to wait for the next higher capacity train and suitable passenger information can be broadcast in the station areas to assist the passengers in making this decision. In extreme cases passengers will embark at different stations if walking distances are comparative.

3.14 Climate

The climate variation in Ottawa is very unique and adds additional burden to the vehicle technology. The wide temperature swings, hot temperatures accompanied by high humidity and cold dry winters with snow and ice serve to provide an inhospitable environment for any vehicle. Most manufacturers are experienced with designing for a wide range of temperatures for their vehicles. However the practicalities of the Ottawa weather with freezing rain accumulation and solar heating are difficult to emulate as tests without significant costs.

As such, to minimise development risk, the vehicle technology should be specified with worst case parameters and wherever possible manufacturers should provide evidence of operation to these extremes or details of the risk mitigation to reduce the effects of climate on operation. A further

precautionary measure would be to ensure that the manufacturer adequately demonstrates compliance to the climate parameters as part of the environmental tests or as part of the warranty period operation.

4. Canadian Transit Systems

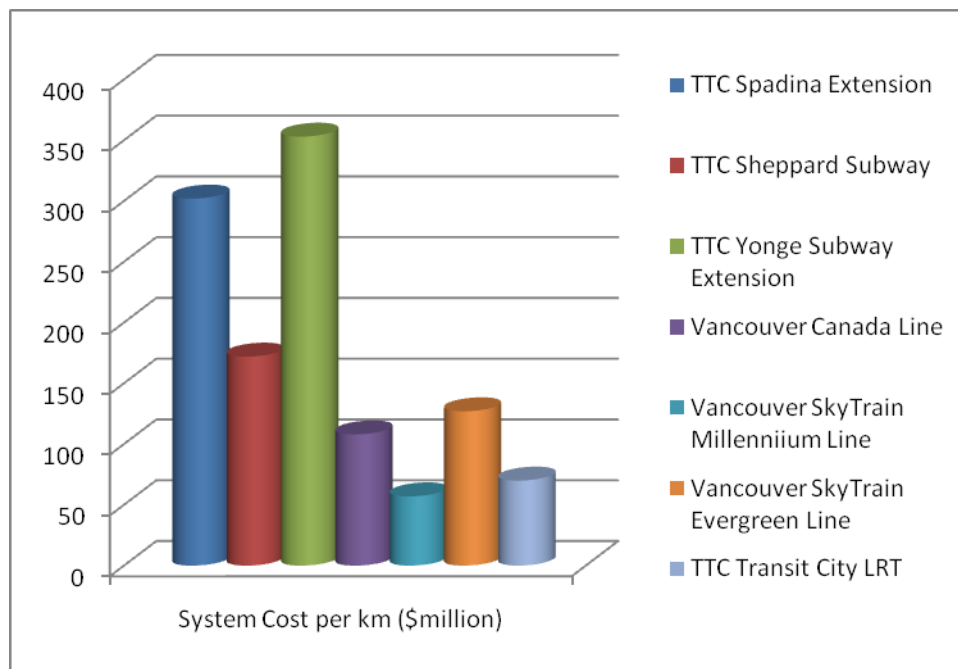
The matrix below provides a comparison of various types of transit in Canadian cities (for the purposes of contrast subway/ metro has been included).

Transit System	Type	Location	Operation	Year of service	Capacity (PPHPD)	Length (km)	#Stations	Overall cost \$Bn ²
Spadina	Subway	TTC	Semi automatic	2015	28,000	8.6	6	2.6
Sheppard subway	Subway	TTC	Semi automatic	2002	20,000	6.4	4	1.1
Yonge Subway extension	Subway	TTC	Semi automatic	2017	28,000	6.8	6	2.4
Canada Line	Light Metro	Vancouver	Automated	2009	15,000	19	16	2.05
Millennium line extension	Light Metro	Vancouver	Automated	2001	15,000	21	13	1.2
Evergreen	Light Metro	Vancouver	Automated	2014	15,000	11	8	1.4
Transit city	LRT	TTC	Driver operation	2012	5,400	122	-	8.5
Calgary	LRT	Calgary	Driver operation	1981	19,440 ¹	44.9	26	0.548
Edmonton	LRT	Edmonton	Driver operation	1978	15,000	12	13	0.357

¹ Current operation is 14580 and future 19,440 PPHPD planned without automation. Maximum theoretical limit is 30,270 PPHPD. Note: Calgary Transit has always planned to move from a surface operation to a tunnel at 8th Avenue Downtown.

² Cost at year of construction.

The following figure provides a graphical comparison of costs. Calgary and Edmonton are not included due to dates of construction and other factors.



The figure shows that a modern subway system can be in the region of \$300million per km, whereas the cost of a completely automated Light-Metro can cost around \$100m per km, and an LRT around \$50-70million per km. For Subway, Light-Metro and LRT there are many factors that could yield significant differences.

4.1 Toronto

Excluding regional transit the City of Toronto rail network is characterised by:

- The subway system, notably the Yonge-University-Spadina Line, the Bloor-Danforth line and the Sheppard Subway. The subway system operates in semi automatic train (STO) operation and provides a relatively high capacity transit system.
- The Scarborough Rapid Transit (SRT) Line, based on an early version of Bombardier's ART technology. The SRT was originally designed to operate in full UTO but was modified to STO, and provides an intermediate capacity transit system, and acts as a lower capacity feeder to the Bloor-Danforth Line with a transfer station at Kennedy.
- The street car system. The street car system operates in manual mode, providing low capacity transit over a limited area, largely the downtown core with frequent stops and low average speed.

The TTC network is based on a higher order (higher capacity) subway system overlaid with a bus network and street car system, with the lower capacity Sheppard Subway and SRT acting as feeders to the subway system. Transfers are required between systems.

Transit City Network

Toronto also has future plans for the Transit City network which will use LRT technology as part of an advance street car system. The vehicles will for the most part run in dedicated lanes in the middle of the street, under manual operation, with frequent stops and, therefore, a relatively low average speed but will also run in underground sections. Capacity is lower than other LRT systems.

4.2 Calgary and Edmonton

The City of Calgary implemented LRT technology with the first phase opening in the early 80's with a number of extensions and expansions.

Both the Calgary and Edmonton LRTs are based on nearly identical driver operated vehicle technology using Siemens high floor vehicles.

At the time of initial construction in the late 70s and early 80s high floor was the state of the art technology and as a result subsequent extensions have also been high floor. While reviews have been undertaken considering conversion to low floor, it has so far not been implemented due to the high conversion costs and impacts on operations with significant down time during conversion. Other Transit authorities worldwide have also chosen high floor so that their vehicles can also operate on existing commuter rail lines that already have high platform stations. Calgary is currently planning for 20,000 PPHPD with a tunnel and an upgrade to a 4 car train consist. Edmonton already has a tunnel and is limited by signalling technology and power supply constraints to 24 trains per hour. The city is now upgrading to 5 car trains and updating its signalling system and power supplies.

4.3 Vancouver

Vancouver currently has two rapid transit systems; the SkyTrain and the Canada Line. A third system, the Evergreen line is also planned as an extension to the SkyTrain system. All three systems can be considered as Light-Metro with full automation and unmanned train operation (UTO), although the SkyTrain and Evergreen technologies are also referred to as Advanced Rapid Transit (ART). The technologies are based on short trains running in full automatic mode with short headways or intervals which allow them to provide significantly greater performance and capacity than other similarly sized systems. Skytrain technology requires full segregation and is operating at capacity, which now entails a costly expansion due to smaller platform sizes.

4.4 O&M Costs

The following table provides transit operating costs for a variety of mainly US based systems for which the same data is collected annually and analysed by the US FTA. The table shows marginal savings for subways compared to LRT. Also shown, and based on the same calculations, is the equivalent cost for Vancouver's SkyTrain. Costs for the Canada Line are not yet available.

Table 1 - Costs /Revenue Vehicle Hour

TRANSIT SYSTEM	TYPE	COST / VEHICLE REVENUE HOUR (\$US 2007)
MTA NYCT	SUBWAY	\$163
CTA	SUBWAY	\$145
BART	SUBWAY	\$249
WMATA	SUBWAY	\$264
MBTA	SUBWAY	\$178

TRANSIT SYSTEM	TYPE	COST / VEHICLE REVENUE HOUR (\$US 2007)
MBTA	LRT	\$210
Minneapolis	LRT	\$168
Houston	LRT	\$236
Pittsburgh	LRT	\$301
MUNI	LRT	\$216
Vancouver SkyTrain	Automated Light-Metro	\$94 (\$CDN 2008)

The results, averaged, are shown in the following figure:

Figure 11 - Average Cost Per Revenue Vehicle Hour

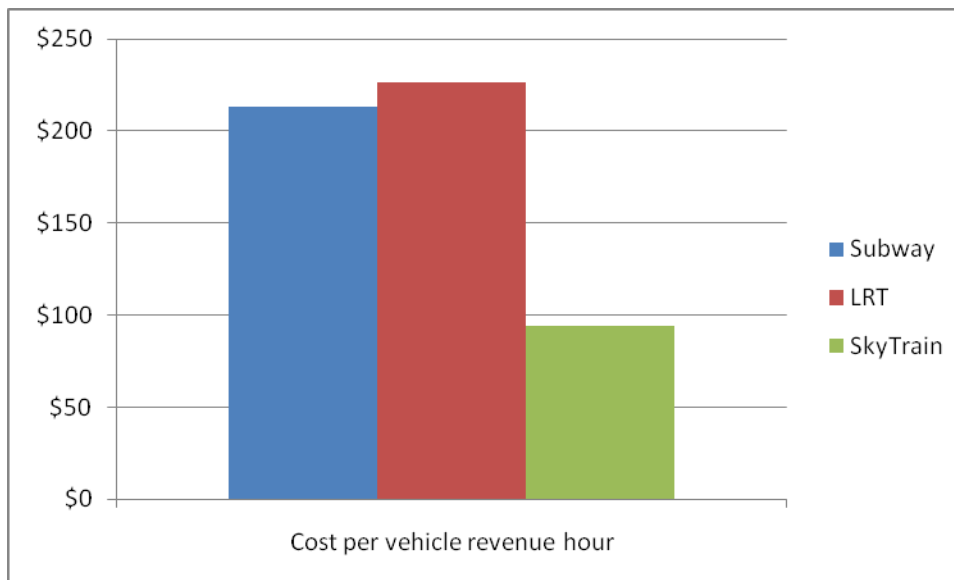


Figure 12 - O&M Costs Per Passenger KM (LRT)

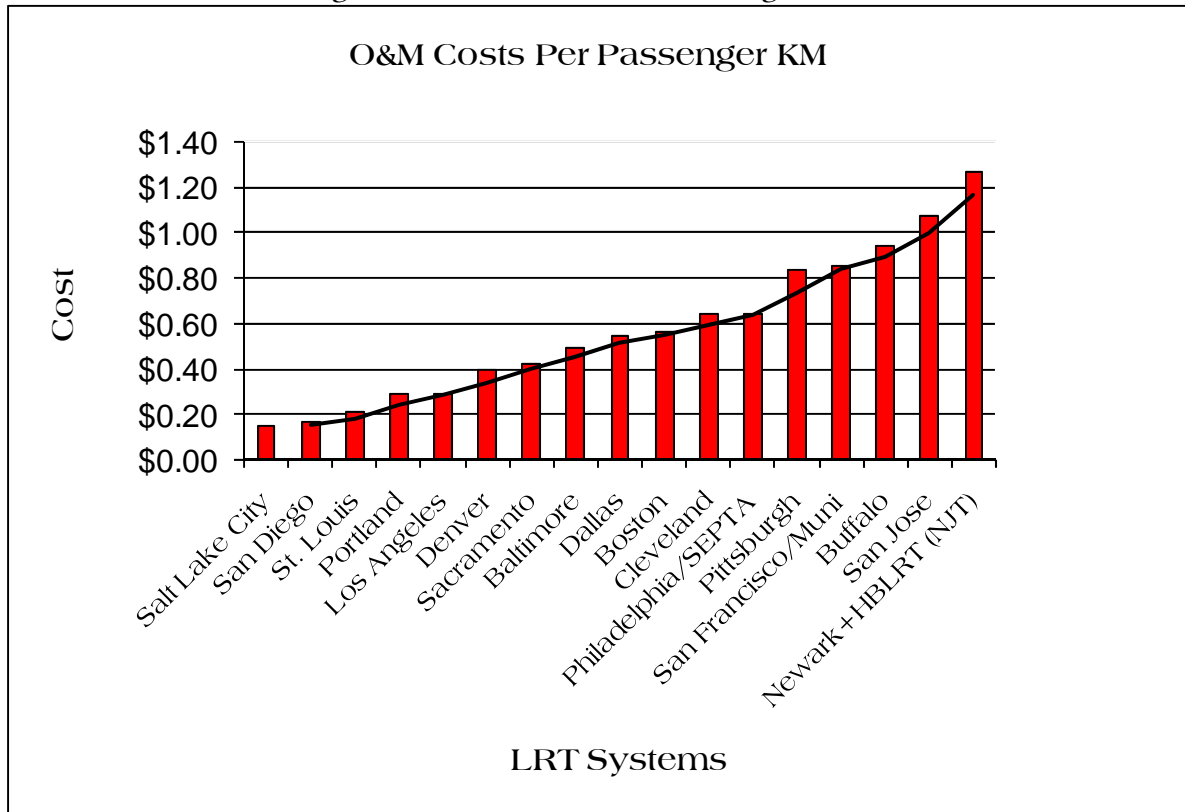
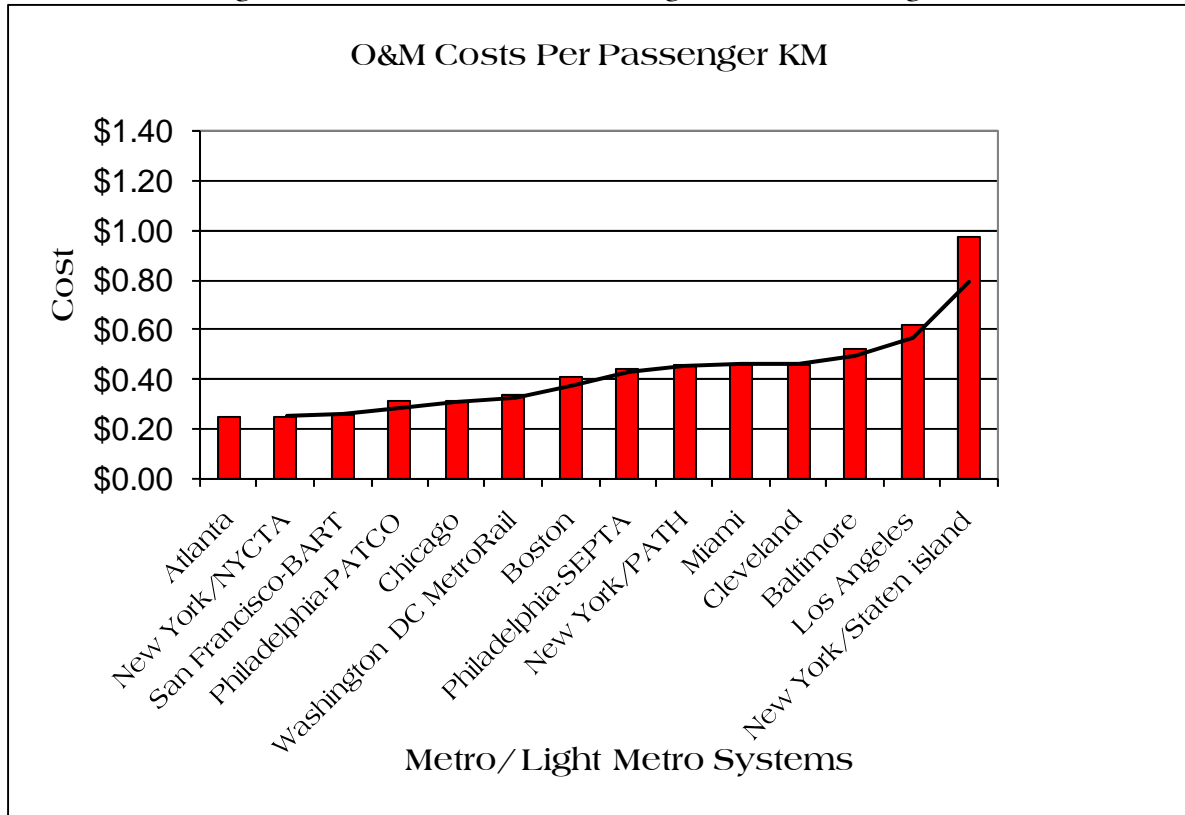


Figure 13 - O&M Costs Per Passenger KM (Metro /Light Metro)



5. Implications of the Application of the Various Possible Options to Ottawa

The table below provides a quick summary of the vehicle technology types applied to Ottawa (Subway/metro has been included for information).

	Capital cost	O&M costs	Capacity risk	Performance risks	Flexibility for future network	Environment / urban impacts	Service
Subway/Metro Spadina, Sheppard, Yonge Subways	High cost	Higher	Meets Capacity and exceeds	Low	Limited adaptation	Medium impact (High floor)	Limited service history in similar climate
Light Metro Canada line, Millennium line, Evergreen	High to Medium costs	Low to medium	Meets Capacity and exceeds	Low	Limited adaptation	Medium impact (High floor)	Limited service history in similar climate
LRT Transit City, Calgary, ETS	Low to medium costs	Low to medium	Meets capacity with automation	Medium	More flexibility	Low impact (Low floor)	Limited service history in similar climate

6. Conclusions and Recommendations

6.1 General

As part of the recommendation process careful consideration of the long term impacts of a technology decision should be made against the possible effects of the choice for operations:

- Up to 2031;and
- Beyond 2031.

The key driver for the transit system is the high peak ridership in the main core corridor in 2031, based on population and employment growth and settlement patterns as outlined in the Official Plan.

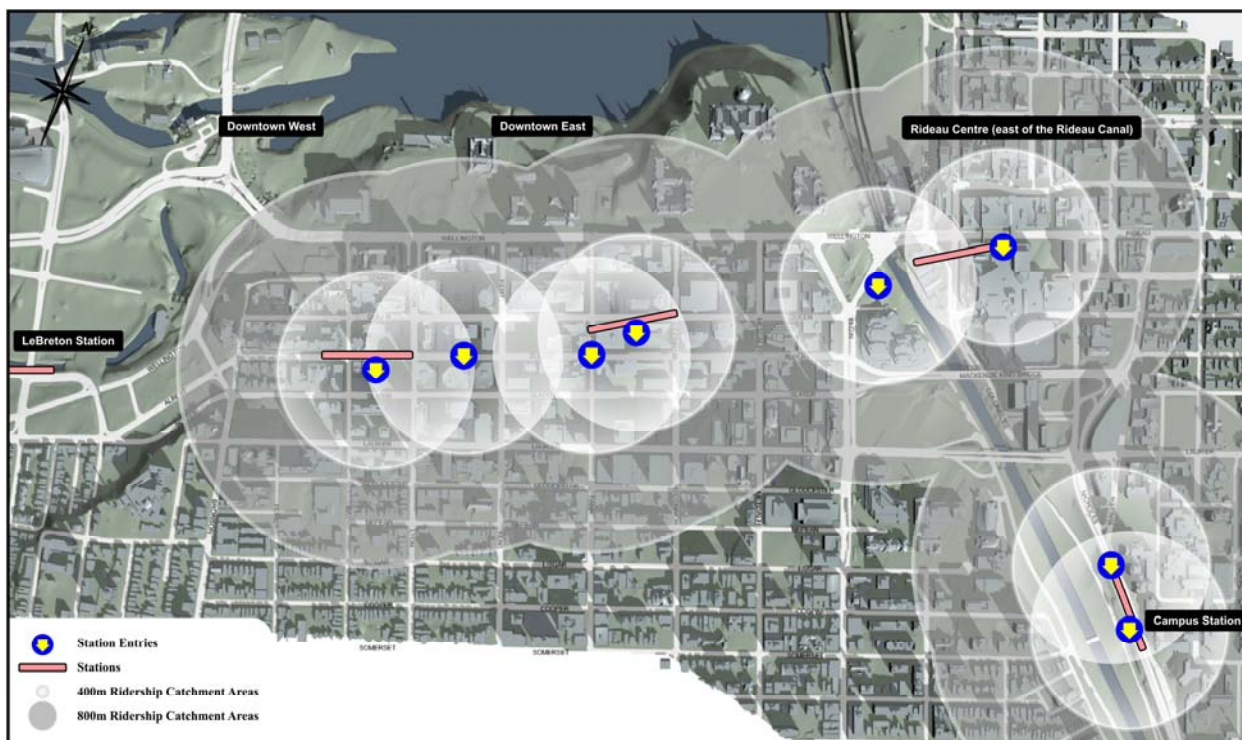


Figure 14 – Ridership Catchment

Figure 14 shows the potential ridership catchment areas surrounding the station entrances. After 2031 it is unlikely that the ridership will exceed predictions as the corridor is already highly developed and constrained with little possibility of development to the north. Beyond 2031 it is unlikely that significant changes in growth patterns will dramatically alter transit use characteristics.

Given the potential ridership capacity of 20,000 PPHPD and capital costs transit technology the recommendation is then limited to two choices:

- LRT
- Light Metro

6.2 Key Discriminating Factors

The key discriminators for the technology and mode selection include:

- Transit System and Network Integration, including fragmentation impacts of multi-modes on:
 - Transfers for passengers
 - Fleet management, including deadheading, with multiple unconnected operations, maintenance and storage facilities
- Degree of segregation
 - Cost of segregation
 - Impact of urban form

These discriminators are dealt with in the following sections, and include other factors that have less influence on the technology and mode selection.

6.2.1 Transfers for Passengers

Transfers will be inevitable but the minimisation of transfers and the reduction of transfer times must be a key goal. The number of transfers is highly dependent on the choice and implementation of transport modes outside the core. Multiple modes of transportation may be detrimental to ridership increases as passengers prefer not to transfer, or will permit at least one transfer between two different modes, or where a change in direction is required. General practice is that passengers will not endure multiple transfers for an onward journey. A development of a Light Metro system in the core will force multiple transfers in the outlying transfer stations. A further challenge of multiple transportation modes is the ability of the modes to synchronise and the minimization of transfer time when moving to a lower frequency service. A single mode of transportation that operates with a mixture of driver operation and automation, with synchronisation at transfer points, provides maximum flexibility to grow and change the system in response to changing demands.

6.2.2 Fleet Management

The choice of developing the core as a Light Metro solution with multiple transportation modes will effectively divide the city into disparate transit groups in the North, South, East and West. The development of the main core as a Light Metro solution would remove any interconnectivity of the outlying regions and they will have to develop their own maintenance centres, operating offices, storage and staff. This will be compounded by the number of alternatives of different transportation modes such as BRT and LRT operating in these regions. A decision to choose a vehicle technology just for the main core will potentially multiply any operational inefficiency associated with running multiple transportation systems. Choosing LRT provides the best long term solution to develop and implement a coherent and flexible system while providing excellent opportunity to minimise overhead costs.

Regardless of any possibility of the rationalisation of maintenance and storage facilities, a result of the fragmentation of the network may be higher operational costs attributed to an increase in deadheading times.

6.2.3 Cost of Segregation

As indicated in the report the real cost of segregation is outside of the main core. The segregated core is largely developed and imposes few constraints to network planning, however the extension of the system into outlying regions will necessitate significant expenditure to ensure that the corridors are segregated. By utilising a vehicle technology which can provide the benefit of driver operation in the outlying suburbs the city has the flexibility of providing signal controlled crossings at major road intersections in the short term to reduce the initial capital cost of the corridor construction. A Light Metro system necessitates a large capital outlay for 'Day 1' operation regardless of ridership, resulting in longer payback periods and potential inefficiency of operation.

6.2.4 Urban Form

Although highly subjective, as Light Metro tends to be high floor the visual impact at street level and in open space is considered significantly less appealing than that of a low floor Light Rail Vehicle (LRV).

Light Metro with on street running is not preferred, but could equally be run with a catenary providing that there is a power supply. Automation and third rail power, normally associated with Light Metro, requires segregation. An advantage of LRT is that it can equally operate in segregated corridors but also can permit 'on street' running with driver operation.

Given the Council-approved Transportation Master Plan and the North-South LRT EA, the development of the South Urban community is based on an integrated urban form, and LRT is the only suitable technology that meets Council's approved plans for this community.

LRT provides an option of a lower profile vehicle technology, which can operate on 'green' track bed and require limited segregation, which are desirable features to minimise the visual intrusion of the system into these sensitive areas. Both vehicle types can be run through the Greenbelt and the impacts can be reduced by careful planting of vegetation and landscaping close to the track. Note, regardless of technology choice, there is always a high possibility that a corridor will create a visual barrier simply by the virtue of the short headways and frequency of operation.

6.2.5 Costs

Figures 4 & 5 provide a comparison of O&M costs for North American LRT and Light Metro/ Metro systems. However caution should be attached to interpretation of these figures as operational and maintenance costs can be determined or affected by a number of differing factors. These graphs should be used as a trend indicator only and a useful comparison between vehicle technologies. The figure shows there is little difference between the two operationally, but do show that automation can play a large part in reducing operational costs, despite being applicable to Light Metro.

6.2.6 Capacity

Both vehicle types have the capability to meet the high density peak. LRT will require some degree of automation or seating/ body modifications to provide the expected capacities. Light Metro has the potential to provide the required capacity with a margin to increase further.

The significantly lower capacity requirements for the extensions present challenges for the design of the operation. Both vehicle types will require a combination of operational features. One feature that will accommodate the reduced capacity on the extension is to have a short turn feature. This will necessitate controlled crossovers at particular station and the ATO functionality to achieve the crossover and short turn in a congruent manner with the headway on the high capacity part of the line. The other feature is the ability to break a train consists into shorter train lengths at particular stations. It is recommended that the reconfiguration of shorter trains into longer trains only occur in the maintenance and storage facility.

Therefore, the ability of the different vehicle types to efficiently accommodate the lower capacity is more related to the train control functionality and not the vehicle type per se.

The capacity requirements should only be considered discriminators for the type of train control technology and specific functionality. A modern ATC system with the ability to achieve headways down to 90 seconds, the ability to carry out 'on-line' train break up, rapid short turn-backs all demonstrate a need to utilise CBTC type technology.

The report therefore considers the capacity requirements are not a discriminator for the choice of vehicle type.

6.2.7 Travel Times

Essentially travel times are similar for vehicle technologies within the main core, and are limited only by the vehicle design, signalling systems and degree of segregation. With multiple transportation modes additional travel time is incurred due to transfer and waiting.

The choice of a vehicle technology must therefore allow flexibility of running within the core and outside the core, to minimise transfers.

6.2.8 Level of Automation

Both LRT and Metro can be automated, although metro systems are most commonly automated due to city requirements to meet high capacities by minimising headways and fleet numbers for denser cities. The density of modern cities that do not have an existing segregated corridor or a developed ridership, normally require a subway or light metro system as the limited construction options dictate a sub-surface transit network.

A level of automation could be phased in at a later stage of the project, but it is normal to implement from the initial installation to minimise disruption to an essential service. Automation can both be applied to LRT and light metro, however reversion to full driver operation is normally only implemented in LRT; light metro tends to revert to a rudimentary emergency or low speed hostling panel.

6.2.9 Headways

Both can have similar headways with automation providing the optimal solution. The potential higher capacity of the light metro allows an increase in headway and more operational flexibility in the event of scheduling changes due to disruption.

6.2.10 Deadheading

The shorter headways of the light metro results in allowing shorter train lengths to meet the peak capacities. The attendant benefits of shorter trains are smaller platforms/stations, more efficient operations, lower deadheading costs, lower energy costs and lower maintenance facility costs.

6.2.11 Reliability

Both vehicle technologies are similar in reliability characteristics and redundant design helps to mitigate potential reliability threats in the design.

6.3 Technology Performance and Recommendations

The choice of technology for Ottawa should be focussed on:

- Maximising the potential for segregation in the main core.
- Ensuring the technology provides the capacity to efficiently meet ridership demand.
- Ensuring the choice of technology can operate outside of the core but retain the flexibility of partially segregated running.
- Minimising or allowing flexibility in construction costs, permitting lower cost alternative construction for corridor development.
- Minimisation of the fragmentation of the transportation network with multiple onward mode choices and transfers.
- Potential savings resulting from bulk purchase of vehicles with other system operators.

- Minimise visual, aesthetic and environmental impact.
- Allowing greater number of bids from suppliers and therefore stimulating competition.

To this we recommend the transit technology choice as being automated LRT which:

- Has less impact on the urban fabric and allows the ability to integrate both non-segregated and segregated systems,
- Provides the necessary capacity for the ridership predictions in the main core,
- Can accommodate low passenger capacity in the extensions outside of the main core,
- Has lower total system capital costs than Light Metro, and
- Can accommodate Ottawa weather conditions.

The vehicle should also have the ability to have in-cab signalling and a driver to permit operation outside the core in partially segregated corridors resulting in a lower cost of segregation with signal controlled crossings in the short term and the minimisation of initial capital expenditure.

By implementing LRT and promoting the use of a single vehicle technology throughout Ottawa, will ensure economies of scale and an improved ability to rationalise staff, equipment and facilities which, in turn, will lead to lower operating costs.

References

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