CITY OF
VANCOUVER

CITY CLERK'S DEPARTMENT
Access to Information & Privacy

File No.: 04-1000-20-2018-472

December 21, 2018

s.22(1) [redacted]

Dear s.22(1) [redacted]

Re: **Request for Access to Records under the Freedom of Information and Protection of Privacy Act (the "Act")**

I am responding to your request of September 5, 2018 for:

> **A copy of any reports or drafts submitted to the City as part of a Streetcar Feasibility Study mentioned in RFP PS20171493 and PS20181398.**
>
> **Date Range: November 1, 2017 to September 5, 2018.**

All responsive records are attached.

Under section 52 of the Act, and within 30 business days of receipt of this letter, you may ask the Information & Privacy Commissioner to review any matter related to the City's response to your FOI request by writing to: Office of the Information & Privacy Commissioner, info@oipc.bc.ca or by phoning 250-387-5629.

If you request a review, please provide the Commissioner's office with: 1) the request number (#04-1000-20-2018-472); 2) a copy of this letter; 3) a copy of your original request; and 4) detailed reasons why you are seeking the review.

Yours truly,

Cobi Falconer, FOI Case Manager, for

Barbara J. Van Fraassen, BA
Director, Access to Information & Privacy
Barbara.vanfraassen@vancouver.ca
453 W. 12th Avenue Vancouver BC V5Y 1V4

*If you have any questions, please email us at foi@vancouver.ca and we will respond to you as soon as possible. Or you can call the FOI Case Manager at 604.871.6584.

Encl.

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Memorandum

Subject	Operations and Maintenance Facility Sizing Information
To	City of Vancouver Project Team
From	Mott MacDonald Canada Limited – Prepared by Rob Evans and Dennis Wu Checked by Katherine Miller and Reviewed by Gary Farmer
Our reference	388583-MMD-00-P0-MO-TR-0002
Date	July 23, 2018 – Rev A

The City of Vancouver has engaged Mott MacDonald to build upon the wealth of previous work, and to imagine Vancouver's streetcar future by incorporating the latest technology trends, planning visions for different areas and City policies into a feasibility study. The Feasibility Study will involve reviewing and updating the streetcar routing, incorporating additional technical detail, developing a high-level ridership forecast, preparing capital cost estimate, benchmarking typical operating costs, and outlining potential funding mechanisms, business case requirements and project next steps. The study will be used by the City as a planning tool to continue to secure space for a future streetcar, identify constraints and confirm network design.

The City has grown and developed over the past couple decades and the property that was previously identified to house the maintenance facility, 800 Quebec Street, is now slated to be developed as part of the Northeast False Creek (NEFC) project. Additionally, the planning vision and area plans for NEFC and the False Creek Flats area have gone through significant changes. Thus, it is necessary to identify a new maintenance facility location, and to update the size requirements to be based on the latest industry best practices and the latest fleet size estimation for the Streetcar network.

The following technical memo has been produced as a guide to advise on the potential size and requirements to be factored in when determining a site location for a new operations and maintenance facility (OMF). The memo has been produced to inform the feasibility study for the City of Vancouver Streetcar project.

To determine the land requirements for the OMF the following have been considered:

- Number of storage tracks
- Number of maintenance bays
- Other facility elements:
  - Wash plant
  - Crew facilities
  - Control room
  - Staff parking

1 Number of Storage Tracks

Based on the current proposed streetcar network, including the Arbutus Greenway, and high-level estimation of speed and run-time, the assumed fleet size at present is 21 vehicles, each 30 m long and 2.65 m wide. The number of storage positions that could be required as a minimum may be taken as 19 or 20 on the assumption that at least one streetcar will be in the workshop undergoing preventative maintenance. However, given the stage of design it is not recommended to work on this minimum allowance. The approach for feasibility design should consider the storage of all 21 cars with an additional empty track that can be used for bypassing storage or as a location to store cars during movements when all storage bays are occupied. The number and length of storage tracks that would be required to accommodate these 21 cars can vary depending on whether they are single ended or double ended.

Single-Ended / Stub-Ended Storage Tracks

For a single-ended scenario, the number of storage tracks that would provide for an ideal situation would be 7 tracks with an additional track or location on site to cater for reversing movements, for instance from the storage tracks to the workshop or vice versa. This would provide 3 cars per track requiring a maximum of 2 cars to be moved clear to get the last car out. This is seen as the maximum number of non-essential moves that will not impact too much on general OMF operations. Anything more than this on a single-ended track would be seen as over complicating site operations.

Double-Ended Storage Tracks

For a double-ended scenario the number of storage bays per track can be increased to an optimum maximum of 6 cars per track. This would require 4 tracks (3.5 occupied) within the storage yard, assuming all storage tracks are the same length although it is most likely that each track will be a different length.

Space for Storage Tracks

The space requirements for these options can be estimated at this initial feasibility stage as follows:

The separation between the cars within the storage area can be anything up to 2 m in width between car bodies. This range of distances allows for anything from two cars adjacent to each other with no infrastructure between them (so a very small gap) to locating a platform between the cars for car access (assuming high floor cars as low floor would not need step access). The separation between tracks and allowance for walkways can often be determined by the level of pre-service inspection that needs to be carried out before the cars enter service. At this feasibility stage, as this is not known it is assumed that a full walk around the car will be required and so walkways are to be provided on both sides. It would be recommended to use 2 m separation which can be refined at a later stage. The clearance between cars longitudinally would need to allow for parking clearance and a walkway for staff. This can be taken as 3 m which would provide a nominal 1m wide walkway and the remainder as a visual stopping distance to the walkway. Taking these in to account the space for a streetcar can be taken as 153.5 m^2 and so a fleet of 21 would equate to an area of 3,682.8 m^2, which also includes an allowance for a bypass/movement track to assist with moving cars around during times of full storage. For the site arrangement an allowance will also need to be provided for the trackwork leading to and from the storage tracks. For a single-ended storage arrangement this could be up to 50% on top of the car storage requiring a total storage area of 5,525 m^2. For double-ended track, the leading trackwork area could need the same size required as the stabling, meaning the total storage area required is 7,365 m^2.

2 Number of Maintenance Bays

The maintenance workshop needs to take account of preventative and corrective maintenance. This will require all possible access to the vehicles full exterior and interior via the use of pits and working platforms. For a fleet size of 21 – 100% low floor cars the recommended number of maintenance bays would be three. These three bays would be made up of two light maintenance bays used for underframe and roof access primarily to gain access to car mounted equipment for maintenance, while the third bay would be used for heavy lifting purposes to remove car bogies.

Spacing between the cars within the workshop would need to take in to account the circulation of both staff and equipment such as forklift trucks. A recommended distance between cars, at this stage of design without knowing the chosen car, would be 4 m between bodysides and a distance of 2 m between bodyside and workshop building. Adjacent to the workshop there will also need to be a number of offices to provide office and welfare facilities for the maintenance staff. As a minimum a 7 m width for the office portion would be recommended if only one level is to be provided. If an upper floor is to be included then the width would need to increase to allow for a corridor linking the rooms on the upper floor. This would require a width of approximately 10 m. Using the wider office width of 10 m to provide the maximum amount of office accommodation within the facility, a workshop building width of 30 m would be adequate for this application. The length of the workshop would need to take into account the car length (assumed to be 30 m), the step access to the pit and workshop floor level surface for circulation and locating removed car equipment. Together this provides a length of 42 m for the workshop, thus providing an overall building area of 1,260 m^2. As with the storage sidings there will need to be an element of trackwork leading to the workshop (and potentially from the workshop if it was to be designed double ended). An allowance of 50% should be included, thus the total area required for the maintenance bays is 1,890 m^2.

As part of the preventative maintenance activities undertaken at an OMF site, the maintenance of wheelsets is of high importance. For a fleet size of 21 cars it is recommended to purchase a wheel lathe to complete the wheel turning in house. Two types of lathe are available for purchase. These are an in-floor lathe over which the car would traverse to the correct position for wheel turning, or a mobile lathe which would pass under a lifted car to the correct position to perform the wheel turning operation. Both of these have benefits and limitations with the main difference being the space requirements for them. An underfloor wheel lathe would require its own bay ideally with sufficient space to allow the full car to be wheel turned whilst under cover, however a mobile lathe could share a bay with the heavy maintenance activities. An indicative size for an extension to the workshop to cater for the mobile wheel lathe would be 66.5 m^2 where as an underfloor wheel lathe would require approximately 1,066 m^2.

Considering the possible expansion of the fleet of streetcars there would be a limitation of the utilization of a workshop containing only 3 maintenance bays. This would be expected to be in the region of 30 cars before an additional maintenance bay would be required to be built.

Within the storage tracks or leading to the workshop there will need to be provision for a delivery track so that the streetcars can be delivered to the OMF site via road transport. This track would need to start by hard standing to allow the road vehicle to approach it and install ramps from the delivery vehicle to the trackwork to the offload the streetcar vehicle. There would be no need for overhead cables in this location as the delivered car will be unpowered. As a rule of thumb, you would generally allow for two car lengths for the position of the road vehicles and the offloaded car which would equate to approximately 348 m^2.

3 Other Facility Elements

Wash plant

Daily washing of the streetcars may be introduced as a requirement to keep the cars presentable all year round and so a wash plant would be required on site. These can vary in length depending on the level of washing required. This ranges from just washing the sides of the cars to washing the sides, front, and rear end. It is assumed at this stage that only the sides of the cars would need to be washed with the front and rear washing being completed manually. A minimum size of wash plant to be accommodated would be approximately 20 m in length and 6 m in width providing an area of 120 m^2. The wash plant would also have an accompanying plant room which contains the pumps and cleaning fluid storage and dispensing systems. A typical plant room would be 10 m by 5 m giving 50 m^2, and total space requirement of the wash plant of 170 m^2.

Substation

Depending on how the OMF site and the portion of the mainline that leads to the OMF are fed with traction power will depend on the requirement for a substation to be located at the OMF site. A typical size could be 200 m^2.

Crew Facilities and Storage

Within the workshop allowance detailed above, there is an allocation for office and welfare space to the side of the workshop portion which measures 10 m wide by 42 m. If this is included over two floors then this will provide 840 m^2. In comparison with an existing facility in the UK with a similar fleet size, the office/welfare and stores space is approximately 3,000 m^2 over two floors. This space includes additional auxiliary workshop space for metal working and welding activities. It is assumed at this stage that the level of metal working activities would not be as high as the older OMF comparison in the UK and so a reduced area would be feasible.

The allocation of office and welfare space noted would be sufficient for the maintenance and driving staff at the site but additional space is likely to be required for storage. As this is feasibility stage an assumed requirement for storage would be in the region of 300 m^2 footprint but would include some storage on an upper floor also.

Control Room

For the overall running of the network a control room will be required. This control room however does not necessarily need to be located at the OMF and could be located off site somewhere. The benefit to having it on the same site keeps all the operations staff together. For similar facilities a control room size of up to 150 m^2 could be utilized that would provide space for a large video screen and individual desks for operators and a supervisor.

Staff Parking

Parking provision would need to be provided for staff working at the OMF site but not for all staff identified below due to shift patterns.

Staffing Level

An assumed staffing level at feasibility stage could consist of the following, which would be refined or adjusted as the project progresses.

- General Manager and PA - 2
- Admin - 2
- Finance - 2
- Operations Manager - 1
- Operations team - 10
- Drivers - 84
- Engineering Manager - 1
- Maintenance Staff - 42
- Infrastructure Manager - 1
- Infrastructure Staff - 40
- Car Cleaners - 20
- Infrastructure Cleaners - 10
- Safety Manager - 1

This allocation would provide a full staff compliment of 216 as an initial high level figure to be reviewed further as the project progresses.

A recommended allocation of parking at this stage of feasibility design could consist of:

- Drivers - 25 (with allowance for shift changeovers)
- General Staff - 4

- Operations Staff - 5
- Maintenance Staff - 20

The parking provision is also based on the assumption that staff who do not need to be onsite prior to the service running would use the system to get to and from work thus reducing the need for parking on site and promoting sustainability.

4 General Site Commentary

The site location for the maintenance facility would benefit from the following attributes:

- Land for additional OMF extension past the current fleet of 21 projected
- The ability to provide a mainline connection that allows for movement in both directions to and from the main line.
- Good road network access.
- Minimal surrounding residential properties.
- Sufficient size to allow for all operational movements to be completed within the boundary of the site and not affect the mainline.
- Ability to turn the Streetcars around so that wheel wear when running on the network is even. This is only really required if there is nowhere on the system that allows the cars to turn around.

Given land availability, there is also a possibility of creating an overbuild development on top of the OMF site. This type of construction does come with its limitations however in that the footprint of the site is likely to increase given the additional structural supports that would be required to support the overbuild development, limited ability to expand in the future, blocking out of natural light and less flexibility in terms of track layout and curves.

Covered storage facilities are also a possibility for additional protection of the cars overnight and when not in service. This type of storage can then lead to smaller development over the top such as car parking.

5 Split Site Facilities

The preference for OMF sites is to contain all facilities required to run the network in one location to provide a single collaborative working location. However, this is not always possible due to land availability and locations of sites. In this case, a split site may be required which could be done in the following ways:

	Site 1	Site 2
Option 1	Full maintenance workshop	Stabling
Option 2	Light maintenance workshop and stabling	Heavy maintenance workshop and stabling
Option 3	Full maintenance workshop and stabling	Small amount of stabling *(potential to place around the system)*

For a fleet size of 21 cars, a recommended split would be to house the workshop in one location with some stabling capacity and the remainder of the stabling at a second location (option 1). The distance the sites are apart would also need to be considered for service running and ensuring that no unnecessarily long empty runs are required. Split site operation can also lead to duplication of facilities such as wash plant (daily servicing) and security presence.

As the fleet grows from the initial size of 21 cars a second OMF site may be preferred. However, if a split site was required at this early stage the split could be for the workshop and stabling of up to 4 cars to be located on one site, and the remaining 17 cars to be stored at a second site.

6 Operations and Maintenance Facility Sizing Calculations

The following table provides a summary of the areas laid out in previous sections.

Table 6-1 OMF Sizing Calculations

	Single MOF Site (m²)				**Split OMF Site (m²)**					
					Workshop and stabling for 4 vehicles				Stabling for 17 vehicles	
	In-floor wheel lathe		Mobile wheel lathe		In-floor wheel lathe		Mobile wheel lathe			
	Dead end storage	Double end storage	Dead end storage	Double end storage	Dead end storage	Double end storage	Dead end storage	Double end storage	Dead end storage	Double end storage
Workshop	2,325	2,955	1,325	1,955	2,325	2,955	1,325	1,955	0	0
Storage/Stabling	5,525	7,365	5,525	7,365	920	1,535	920	1,535	4,605	6,140
Delivery track	350	350	350	350	350	350	350	350	0	0
Wash Plant and plant room	170	170	170	170	170	170	170	170	170	170
Stores	300	300	300	300	300	300	300	300	0	0
Control Room	150	150	150	150	150	150	150	150	0	0
Parking	1,245	1,245	1,245	1,245	1,035	1,035	1,035	1,035	205	205
Substation	200	200	200	200	200	200	200	200	200	200
Circulation Space 20%	2,055	2,545	1,855	2,345	1,090	1,340	890	1,140	1,035	1,345
Total (m²)	**12,320**	**15,280**	**11,120**	**14,080**	**6,540**	**8,035**	**5,340**	**6,835**	**6,215**	**8,060**
Average area per vehicle (m²)	587	728	530	670	1635	2009	1335	1709	366	474

7 Existing Maintenance and Storage Facilities

As mentioned, a single maintenance and storage location is ideal. However, without sufficient land availability or with a need to accommodate a large fleet size, such as in Seattle and Toronto, respectively, multiple facilities may be required.

The majority of streetcars are typically not under cover when stored overnight as maintenance buildings can only offer covered storage for a very limited number of cars. Portland and Atlanta have constructed the maintenance and storage facility under an elevated section of their interstate highways to provide cover for their cars which is advantageous but not always necessary.

Below are examples of maintenance and storage facilities for light rail and streetcar systems in the UK and North America. These facilities can be used for relative size comparison as well as facility layout examples.

Table 7-1 Example OMF Sizes on Other Systems

Location	Number of vehicles stored	Vehicle Dimensions		Depot Size (m^2)	Average area per vehicle (m^2)
		Length (m)	Width (m)		
Gosforth Depot, Newcastle	90	27.40	2.65	59,000	656
Nunnery Depot, Sheffield	32	34.8 (25 vehicles) 37.2 (7 vehicles)	2.65	23,600	738
Gogar Depot, Edinburgh	27	42.08	2.65	68,500	2,537
Wednesbury Depot, Birmingham	21 (30+ potential)	33.00	2.65	40,000	1,905 (1,333)
Therapia Lane Depot, Croydon	34	30.10 (24 vehicles) 32.37 (10 vehicles)	2.65	28,500	838
Trafford Depot, Manchester	95	28.40	2.65	64,000	674
Starr Gate Depot, Blackpool	18	32.23	2.65	13,250	736
Wilkinson Street Depot, Nottingham	37	33.00 (15 vehicles) 32.00 (22 vehicles)	2.40	31,000	838
Portland Streetcar Depot, Oregon	15	20.13	2.46	8,500	567
Seattle Streetcar Depot, Washington South Lake Union	11	20.13	2.46	3,350	305

Location	Number of vehicles stored	Vehicle Dimensions		Depot Size (m^2)	Average area per vehicle (m^2)
		Length (m)	Width (m)		
Seattle Streetcar Depot, Washington Chinatown - International District	8	20.13	2.46	3,200	400
Toronto Streetcar Depot, Ontario Roncesvalles Carhouse	60	30.18	2.55	18,200	303
Toronto Streetcar Depot, Ontario Russel Carhouse	40	30.18	2.55	16,500	413
Toronto Streetcar Depot, Ontario Leslie Barns	164	30.18	2.55	65,000	396
Tucson Streetcar Depot, Arizona	9	20.13	2.46	5,300	589
Atlanta Streetcar Depot, Georgia	6	24.11	2.65	10,000	1,667

8 Conclusions

Laid out in this memorandum is a conservative estimation of OMF sizing. This aims to aid in the initial search for sites, but it should be noted that trackwork geometry may have an impact on the sizing requirements depending on the types of turnouts used.

As a sense check, the average areas per vehicle laid for the different OMF layout scenarios in Table 6-1 can be compared against the average areas per vehicle of existing OMFs in Table 7-1. In comparison, the OMF areas in Table *6-1* do fall within the typical range of the existing OMF examples. The single OMF site has a similar area per vehicle to those with similar vehicles sizes and storage capacities. While the split OMF site does have a larger average area per vehicle as some OMF infrastructure may be duplicated.

Overall, the average size of an OMF is highly dependent on several factors including property availability and constraints (i.e. size, shape, etc.), and the operational requirements. A larger fleet size accommodated on one site typically has a lower average area per vehicle as the infrastructure is not duplicated and layout efficiencies can be realized.

In conclusion, the sizing requirements should be used as an initial guide only for further development as design work commences. They are based on best practices for maintenance and stabling facilities. The requirements for the Vancouver streetcar network may be adjusted as the project develops and more clarity on how it will be operated and maintained, and by whom, is achieved. Additionally, the shape of the site is also very important when trying to achieve a useable layout. Triangular and rectangular sites tend to lend themselves to more efficient operational layouts rather than long thin or square sites.

Memorandum

Subject	Streetcar System Benchmarking Information
To	City of Vancouver Project Team
From	Mott MacDonald Canada Limited – Prepared by Dennis Wu Checked by Katherine Miller and Reviewed by David Harris
Our reference	388583-MMD-00-P0-MO-TR-0003
Date	August 10, 2018 – Rev A

The City of Vancouver has engaged Mott MacDonald to build upon the wealth of previous work, and to imagine Vancouver's streetcar future by incorporating the latest technology trends, planning visions for different areas and City policies into a feasibility study. The Feasibility Study will involve reviewing and updating the streetcar routing, incorporating additional technical detail, developing a high-level ridership forecast, preparing capital cost estimate, benchmarking typical operating costs, and outlining potential funding mechanisms, business case requirements and project next steps. The study will be used by the City as a planning tool to continue to secure space for a future streetcar, identify constraints and confirm network design.

Benchmarking against other streetcar systems will help to determine the optimal design guidelines and principles for the Vancouver Streetcar Network. By mimicking the successful streetcar systems and learning from the challenges of others, the Vancouver Streetcar Network can properly assemble its system to support Vancouver's transportation needs and build towards a greener future. The system benchmarking research outlined in this memorandum builds upon the Streetcar Principles Report (388583-MMD-00-P0-RP-TR-0001). The following technical memo has been produced to review a few key parameters that were identified by the City initially and during the Streetcar Principles Information Session on June 4, 2018. These include bike-track interaction best practices and commentary on the effects of traffic operations on streetcar performance.

The following topics are included in this memorandum:

- Benchmarking Against Other Streetcar Systems
- Streetcar Vehicle Sizes and Capacity
- Bike-Track Interaction
- Traffic Operations Affecting Performance

1 Benchmarking Against Other Streetcar Systems

As the Vancouver Streetcar Study progresses and refreshes some of the assumptions from the *2005 Downtown Streetcar Design, Layout and Ridership Study,* a refreshed comparison of other streetcar systems can be done. The following table below summarizes key operating parameters of several existing streetcar systems in North America and internationally.

Table 1: Summary of Other Streetcar System Operating Parameters

Location	Streetcar Name	Total Fleet Size	Frequency (min)	Average Daily Ridership	Total Length (km)	O&M Cost	Max Vehicle Speed
Portland	Portland Streetcar	17	12-15	15,139	19.3	$184 CPRH[2]	70
Seattle	Seattle Streetcar	10	10-15	4,436	6.1	$16-24 MPY[1]	70
Atlanta	Atlanta Streetcar	4	10-15	1,200	4.3	$3.6 MPY[1] $148.48 CPRH[2]	
Toronto	Toronto Streetcar	204	10	292,100	83	$2 MPY[1]	70
Tucson	Sun Link	8	10 during the day 15 morning/evening 30 midnight – 2am	2,613	6.3		70
Salt Lake City	S Line		20	1,087	3.2		
Washington DC	DC Streetcar	6	12	3,655	3.9		70
Dallas	Dallas Streetcar	4	20	600	3.9		77
Cincinnati	Cincinnati Bell Connector	5	12-20	1,585	5.8	$4.2 MPY[1]	70
Detroit	Q Line	6		3,000	5.3	$6 MPY[1]	77
Birmingham	West Midlands Metro	21	6-8 during the day 15 evening/Sunday	17,000	20.9		70

[1] CPRH = Cost Per Revenue Hour = Cost of operating one streetcar in service for one hour
[2] MPY = Millions Per Year

Service Frequency

The *2004 Benchmarking Exercise: 6 Streetcar Systems Around the World Report* states that frequencies at peak service typically operate between 6 – 10 minutes and 12 – 20 minutes during off-peak service while the *Tourist and Recreational Usage of Proposed Downtown Streetcar Report* recommends service frequency to be 10 minutes or less. It is recommended that the Vancouver Streetcar use the 8-minute peak service frequency that was assumed in the *2005 Downtown Streetcar Design, Layout and Ridership Study* and Arbutus Greenway Project. Additionally, the 8-minute peak service aligns with TransLink's frequent transit network service definition. In comparison, 8-minute peak service is similar to Birmingham Midland Metros peak frequency and higher than most North American streetcar systems.

System Reliability

Reliability is an important factor to customer satisfaction and trust, as well as to business operations. As mentioned in Paula Nguyen's thesis, *Determining the Factors that Influence the Odds and Time to Streetcar Bunching Incidents,* vehicle bunching is often the result of unreliable service when consecutive vehicles fail to maintain their schedule. A delayed vehicle will tend to carry more passengers and be further delayed while the trailing vehicle will carry fewer than expected passengers and be further ahead of schedule. APTA's Modern Streetcar Vehicle Guideline states that reliability impacts the schedule recovery component time, which can result in increased operation costs when more vehicles need to be introduced into the system to meet the required frequency.

The Toronto Transit Commission, operator of the Toronto Streetcar System, posts a Daily Customer Service Report to detail how their service compares to their target goal. The Toronto Streetcar expectation is to be on schedule at least 90% of the time for departures from end terminals. However, the actual metric regularly hovers around 60%, far lower than their subway services (Lines 1-4) and busses, as shown in Figure 1.

Report for Tuesday, July 31, 2018

	Service:	Our objective:	Our target:	Actual:	How we did:
1	Yonge-University	Deliver a punctual service[1]	96%	94%	✗
2	Bloor-Danforth	Deliver a punctual service[1]	97%	98%	✓
4	Sheppard	Deliver a punctual service[1]	98%	100%	✓
3	Scarborough	Deliver a punctual service[1]	96%	100%	✓
	Bus	On time departures from end terminals [3]	90%	75%	✗
	Streetcar	On time departures from end terminals [3]	90%	55%	✗
	Elevator	Provide easy access[2]	98%	100%	✓
	Escalator	Provide easy access[2]	97%	98%	✓

Legend

[1] % of Service (up to Headway + 3 minutes)
[2] % of devices available
[3] % of service (end terminal departures between +1 minute early and -5 minutes late)

Figure 1: Toronto Transit Service Reliability
(Credit: Toronto Transit Commission Daily Customer Service Report)

Toronto streetcar similarly runs in mixed traffic on the majority of its routes. But to combat traffic congestion and service delays, dedicated rights-of-way are being constructed for new track expansions. Additionally, the Toronto Transit Commission has implemented a streetcar pilot program on King Street, the busiest surface transit route in the city, where through movements are not allowed for cars, and bike lanes have been removed in hopes of improving streetcar travel times. Cars are able to travel along King Street one block at a time as only right turns are permitted as shown in Figure 2. The pilot program will investigate potentially transforming King Street to a transit-priority street between Bathurst Street and Jarvis Street. As of April 2018, there has been an increase in transit reliability as 85% of streetcars are arriving within 4 minutes westbound during the morning commute. There has also been improvement in the reliability of streetcar travel times with a an approximately 5 minutes improvement (in each direction) during the afternoon commute for the slowest streetcar travel time.

Figure 2: Toronto Streetcar King Street Pilot
(Credit: King Street Transit Pilot: Monitoring and Evaluation Report)

Portland's Streetcar performance is measured similarly to Toronto as on time service is defined as between 1.5 minutes early to 5 minutes late. However, the parameter is measured at specific time-points as opposed to strictly at end terminals. As mentioned in the Portland Streetcar Strategic Plan 2015 – 2020, Portland's performance goal is to be on time 85% of the time for all three of its streetcar lines as they currently hover around 80% on time. A map of Portland's Streetcar network can be found in Appendix A.

The table below details the yearly averages of Portland Streetcar's on-time performance:

Table 2: Portland Streetcar's On-Time Performance

Line	On Time	Late	Early
NS Line	83.2%	8.0%	8.9%
A Loop	83.5%	8.6%	8.0%
B Loop	78.5%	14.6%	6.9%

(Credit: Portland Streetcar Ridership Performance)

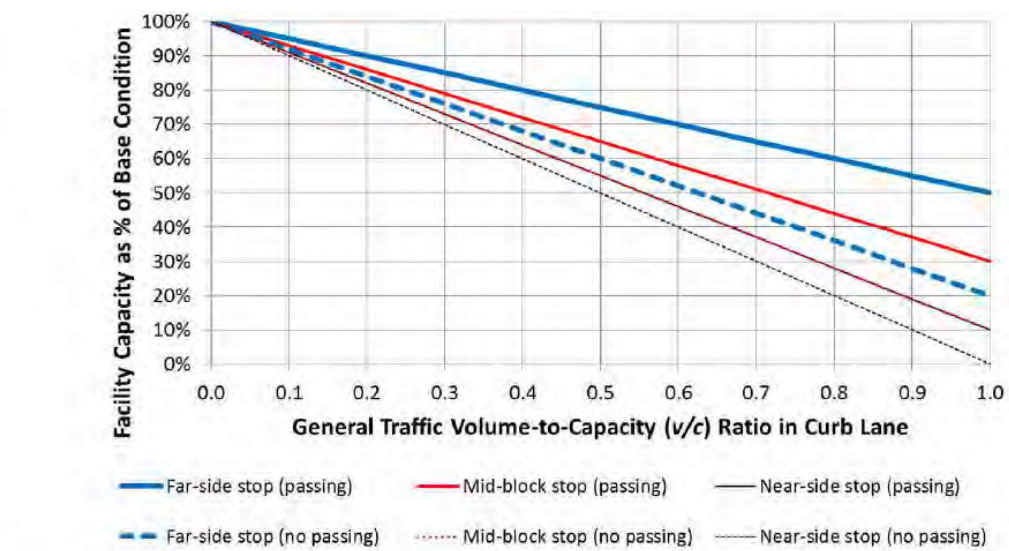
Portland streetcar primarily runs in mixed traffic with no traffic-signal prioritization. By running in mixed traffic and thus, not requiring segregated guideways, the cost of construction is reduced, disruption to existing traffic flow is minimized and curbside parking can be retained. However, slower operating speeds are inevitable.

At this time, it is not appropriate to set reliability targets but it is worth keeping them in mind as the streetcar study progresses and decisions on streetcar priority are made. Instead, understanding how traffic operations affect streetcar performance is recommended.

2 Traffic Operations Affecting Performance

No standard has been developed to determine whether a certain volume of traffic warrants segregated-running streetcar or to determine what can be considered an acceptable delay. As mentioned in *388583-MMD-00-P0-RP-TR-0001 - Streetcar Principles Report*, Zurich Public Transport (VBZ) uses the performance guidelines of no more than a 10 second delay at signalized intersections and travel time variability of no more than +/- 5% over the whole route. General design principles, such as no parking, traffic signal prioritization and vehicle segregation at intersection approaches, can be considered to minimize delay to streetcar operations when in-street shared running with general traffic.

Figure 3 describes the relationship of streetcar capacity when operating in mixed traffic or semi-exclusive guideways, both of which allow cars to enter transit curb lanes to turn right. As the volume of non-transit movements using the curb lane increases relative to the curb lane's capacity for serving those movements increases, streetcar capacity decreases. Far-side stops provide greater capactiy than mid-block or near-side stops. The below figure represents both bus and streetcar capacity. However, since streetcars are restricted to its tracks and therefore, unable to pass, only the dotted lines are representative of streetcar capacity. When streetcar vehicles are segregated from regular traffic (v/c = 0), capacities are highest.



Source: Calculated using TCQSM methods.
Notes: Base condition assumes that only transit vehicles are allowed to use the curb lane.
"Passing" indicates ability of buses to leave the curb lane to pass stopped vehicles.
"Mid-block (no passing)" and "Near side (passing)" have the same characteristics.

Figure 3: Impact of Curb Lane Traffic Congestion on Streetcar Capacity
(Credit: TCRP Report 165)

To determine if the streetcar should be segregated-running or in-street shared-running, many considerations need to be made to ensure consistent performance of the streetcar system. These include, but are not limited to, analysis of traffic volumes, assessment of street parking and examination of access and circulation.

3 Streetcar Vehicle Sizes and Capacity

Vehicle dimensions are important to consider because it alters many aspects of the project including platform designs, vehicle interior layouts and roadway geometry, to name a few. Routing can also be affected as streetcar stops need to be positioned at city blocks that have sufficient length. It is critical to acknowledge all these factors when determining the vehicle size to ensure the streetcar system is successful. The following sections outline typical vehicle dimensions for a selection of streetcar systems.

Vehicle Width

APTA's Modern Streetcar Vehicle Guideline states that streetcar vehicles in Europe have been standardized to be one of 3 different widths; 2.3 m, 2.4 m or 2.65 m. The 2.3 m vehicle width is uncommon in newer systems and is typically used for special cases with narrow corridor constraints. In the United States, 2.46 m vehicle widths are also used, which are based on Czech vehicle designs. The widths discussed are maximums of the car body and do not include door threshold extensions.

In the systems that have been reviewed, vehicle widths are either 2.46 m or 2.65 m, with the exception of Toronto, where vehicles are an intermediate width of 2.55 m.

The Streetcar Principles Report recommends the Vancouver Streetcar vehicle width to be the upper limit of the typical range of streetcar widths of 2.65 m to maximize capacity constraints.

Vehicle Length

Streetcar vehicle lengths can vary greatly from 20 m to over 40 m. North American vehicle lengths are on the shorter end of the spectrum (20 m) due to lower ridership figures and less demand. Cities that have limited space availability prefer shorter vehicle lengths as longer vehicles require longer stop platforms, which may conflict with the existing layout of city blocks.

In the North American systems reviewed, over half of the vehicle lengths are 20 m. Toronto and Birmingham have vehicle lengths of 30 m or greater due to their high ridership and the need for higher capacities. Cities, such as Cincinnati, Salt Lake City and Atlanta have opted for vehicle lengths between 20 m – 30 m.

The Streetcar Principles Report recommends the Vancouver Streetcar vehicle length to be a nominal length of 30 m with the platform length to be 35 m. As mentioned in the Streetcar Principles Report, vehicles up to a length of 40 m could still be accommodated as long as the vehicle doors are positioned to stop within the platform.

Vehicle Capacity

APTA's Modern Streetcar Vehicle Guideline states that vehicle capacity is a function of vehicle length and layout, and can range from approximately 100 people to over 200 people. Overall system capacity is dependent on not only vehicle capacity, but also frequencies and system operating speeds.

Below is a summary of the vehicle widths and lengths and total vehicle capacity of each streetcar system reviewed:

Location	Streetcar Name	Vehicle Manufacturer	Vehicle Width (m)	Vehicle Length (m)	Total Vehicle Capacity	Frequency (min)	System* Operating Speeds
Portland	Portland Streetcar	Skoda Inekon United Streetcar	2.46	20	140	12-15	14.71
Seattle	Seattle Streetcar	Inekon	2.46	20	140	10-15	13.90
Atlanta	Atlanta Streetcar	Siemens	2.65	24	195	10-15	
Toronto	Toronto Streetcar	Bombardier	2.55	30	251	10	
Tucson	Sun Link	United Streetcar	2.46	20	156	10 during the day 15 morning/evening 30 midnight – 2am	
Salt Lake City	S Line	Siemens	2.65	24	195	20	
Washington DC	DC Streetcar	Inekon United Streetcar	2.46	20	157	12	
Dallas	Dallas Streetcar	Brookville	2.46	20	125	20	
Cincinnati	Cincinnati Bell Connector	CAF	2.65	23	154	12-20	
Detroit	Q Line	Brookville	2.46	20	125		
Birmingham	West Midlands Metro	CAF	2.65	33	210	6-8 during the day 15 evening/Sunday	

* = Revenue kilometres per revenue hour

The following table outlines the vehicle width, length and capacity recommended in the Streetcar Principles Report:

Vehicle Width (m)	Vehicle Length (m)	Total Vehicle Capacity
2.65	30	200

4 Bike-Track Interaction

As more cities begin to consider LRT and streetcar technology while continuing to expand their cycling networks, bike-track interaction is an evergrowing discussion to find a standard solution which guarantees the safety of cyclists along streetcar routes. Since the width of the wheels of bicycles are smaller than the flange gap of streetcar tracks, cyclists have lodged their wheels in the tracks and have been thrown off their bicycles, resulting in serious injuries. Currently, a variety of solutions have been implemented on different systems to help mitigate the number of such occurrences, but a standard solution to eliminate this safety hazard has yet to be developed and adopted by streetcar systems. It is also worth noting that it is likely that a "one size fits all" solution is not widely used as each streetcar system and the city it operates in has different contexts.

Angle of Cyclist Crossing with Streetcar Tracks

Separation between streetcar tracks and bike lanes is ideal to eliminate the chance of a bicycle wheel being caught in the flange gap. Therefore, whenever possible, streetcar tracks should be left-side or centre running while bikes are on the right-side of the street to minimize bike-track interaction conflict. However, when a streetcar track curves and crosses a bike path, cyclists are recommended to cross the tracks at a close-to-perpendicular angle. Safe crossing of the tracks can be promoted by designing the angle at which the bike path and track intersect to be over 60 degrees. Additionally, signs can be posted to warn cyclists of the possible hazard. Portland has implemented signs such as Figure 4, and pavement markings to inform and direct cyclists safely across the tracks.

Figure 4: Portland Signage
(Credit: Portland Tribune – Are Portland Streetcar tracks dangerous for bicycles?)

Flange Filler Material

There is ongoing research being performed to develop a durable and elastic material that fills the flange gap and remains decompressed for cyclists and other users that have wheels; such as wheelchairs, walkers, strollers and rollerblades, while also being able to temporarily compress under the greater loads for streetcar. Rubber has been tested as the flange filler material; however, it currently deteriorates quickly and requires onerous maintenance, making the flange filler costly and inefficient if used along the entire track network. Seattle has identified specific intersections with high traffic crossings, such as the intersection of S Lane St and 8th Ave S, and have used rubber flange filler at the crosswalks.

Public Education Programs

Another mitigation is to inform the public about the safety hazards around the streetcar. One example is in Seattle where they have implemented education programs to encourage cyclists to use specific streets that have segregated bike paths running parallel to streetcars and to inform cyclists of safety tips when riding near streetcars or crossing streetcar tracks, as shown in Figure 5. It's important to also educate streetcar users, road users and pedestrians on how to interact with cyclists.

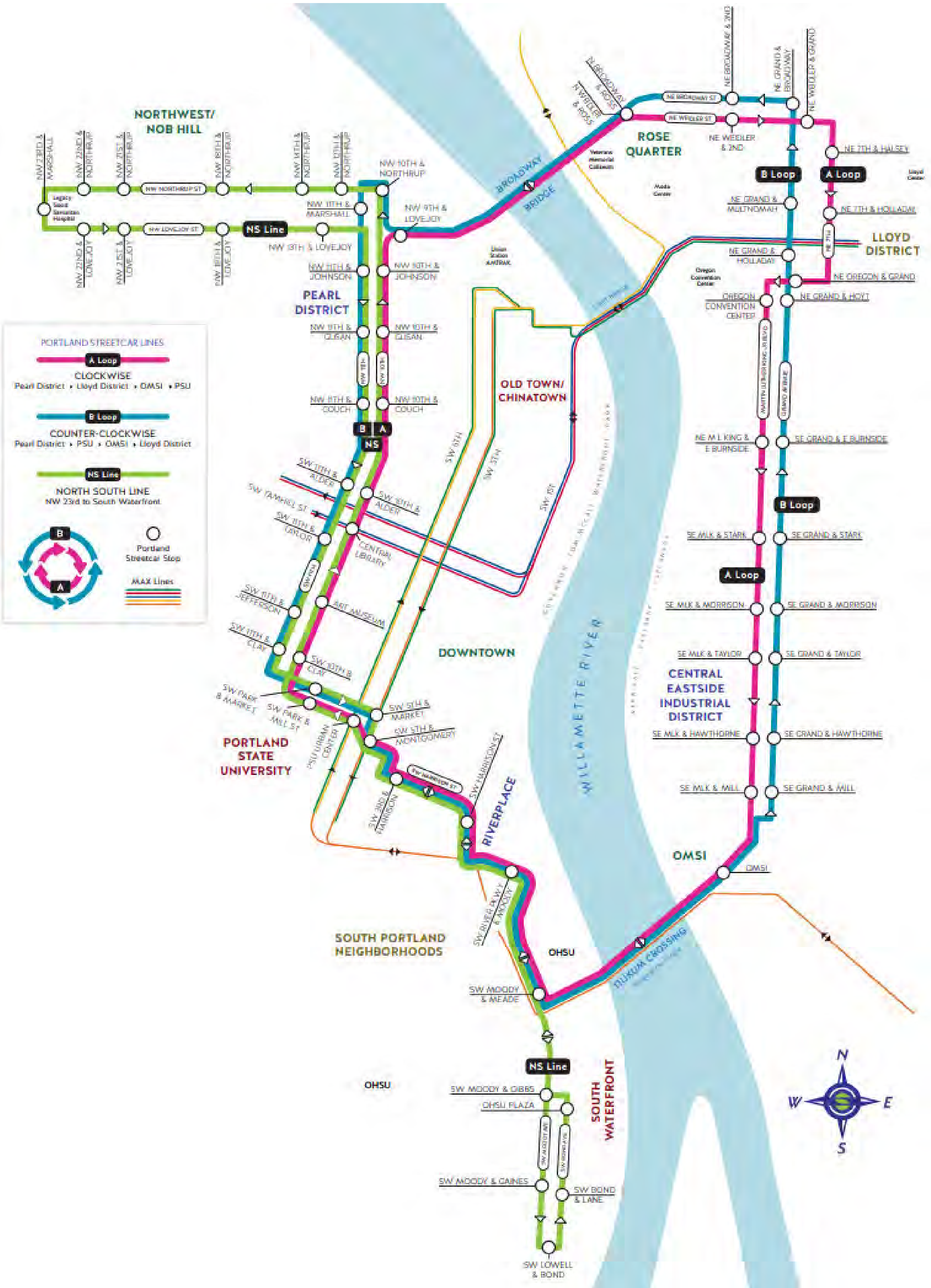
Figure 5: Seattle Streetcar Safety Brochure
(Credit: SDOT & City of Seattle - Seattle Streetcar Map Brochure)

As the development of the feasibility study continues, all angles of Vancouver Streetcar bike-track crossings will need to be closely considered. Additionally, all high-volume crossings need to be identified to assess the potential of installing flange fillers. Since flange fillers cannot be installed across the entire network, it is crucial that an education program be implemented to inform cyclists of safety tips when around the streetcar system, particularly the crossing of the streetcar tracks. Furthermore, it is equally as important to educate the public of safe interaction with all modes of transportation, whether that be walking, cycling, driving, bussing or taking the streetcar.

5 Next Steps

Going forward, the findings from the benchmarking research will be used as reference and built upon as the Vancouver Streetcar Study progresses. The commentary in this memorandum will help inform decisions and assumptions that are to be made, as well as be incorporated into the final Feasibility Study Report.

Appendix A: Portland Streetcar Map



(Credit: Portland Streetcar – Maps & Schedules)

City of Vancouver Streetcar Feasibility Study

Streetcar Design Considerations Report

August 16, 2018

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Contents

List of Figures

List of Tables

Executive Summary

The City of Vancouver Streetcar Feasibility Study will build upon the wealth of previous work, to imagine a comprehensive future streetcar network for Vancouver by incorporating the latest technology trends, planning visions for different areas and City policies into a feasibility study. The study outcomes will enable the City to plan its streets and development to facilitate the introduction of a modern streetcar in the future. The study will be used by the City as a planning tool to continue to secure space for a future streetcar, identify constraints and confirm network design.

This Streetcar Design Considerations Report contextualizes considerations for planning and design of streetcar. It introduces modern streetcar as being within the class of modern low floor, urban style Light Rail Transit (LRT). The vehicles are sleek and modular with typically higher capacity, possibly increased speed, smoother ride, and are more accessible than older style streetcar systems and modern buses. They are sometimes laid out with fewer stops and more definitive physical segregation from other road users to provide a high level of service reliability.

To implement modern streetcar within the City of Vancouver, policy context should be considered, in addition to universal accessibility design approach, while following best practices and industry technical guidelines. Streetcar vehicles and track geometry have spatial requirements that typically impose the most constraints on the development of a streetcar system. Vehicles are typically 30 m long and 2.65 m wide, and typically maneuver through curves as tight as 25 m and on hills as steep as 8%.

There are many, and varied, considerations for integrating streetcar into a multimodal urban context through various priority measures such as levels of segregation or signal priority. This report presents the best practices and possible options for implementing streetcar, as well as considerations for integration with other modes. These will help ascertain the City of Vancouver's preferred approach to some of the overarching design assumptions and challenges described, but also lays out recommendations and design guidelines. This will inform the development and confirmation of the streetcar routing, phasing and implementation, and feasibility study.

Streetcars can be run in-street within shared lanes or segregated rights-of-way. The location of the track within the street right-of-way is dependent on the desired integration, or separation, with other modes and safety measures. Streetcar reliability and travel time is significantly impacted by its performance through intersections. Unlike other random events that can affect travel times, delays at intersections can be largely mitigated in design, primarily through traffic control systems and strategies. These can range from straightforward strategies that simply provide green lights to the streetcars to more complex strategies that look to provide a balance between the streetcar operation and that of the remaining traffic.

When implementing a streetcar system there are ancillary considerations including stops, track types, traction power and other systems requirements. The stop type, centre load or side load, will be dependent on the track alignment as well as how the streetcar is to be integrated into the street, and the features can be minimal, similar to bus stops. The track type is also dependent on the context in which the streetcar is being implemented. If the streetcar is in-street shared running then it will require embedded track, with the top-of-rail flush with the top of asphalt, to allow road vehicles to drive in the lane. If the track is segregated, the track type can be embedded, direct-fixation, ballasted or green track, which has noise and microclimate benefits but does have a cost premium.

Overall, there are many considerations and design parameters that must be accounted for and utilized when developing designs for future-proofing for streetcar. These are captured within this report, and a brief recommended design guideline is provided in Section 5 that will be used when developing concepts for the Feasibility Study.

1 What is Streetcar?

The concept of “streetcar” tends to evoke images of small heritage vehicles trundling through mixed traffic, or Toronto’s classic red high-floor streetcars (Figure 1-1). However, modern streetcar systems in North America (see Figure 1-2, Figure 1-3 and Figure 1-4) can best be described within the class of modern low floor, urban style Light Rail Transit (LRT). The vehicles are sleek and modular with typically higher capacity, possibly increased speed, smoother ride, and are more accessible than older style streetcar systems and modern buses. They are sometimes laid out with fewer stops and more definitive physical segregation from other road users to provide a high level of service reliability.

Figure 1-1 Toronto Streetcar, High Floor Vehicles

Figure 1-2 Portland Streetcar

Figure 1-3 Atlanta Streetcar

Figure 1-4 Salt Lake City S-Line

The American Public Transit Association (APTA) defines streetcars as:

Lightweight passenger rail cars operating singly (or in short, usually two-car, trains) on fixed rails in right-of-way that is not separated from other traffic for much of the way. Light rail vehicles are typically driven electrically with power being drawn from an overhead electric line via a trolley or a pantograph.

The Transportation Research Board's Transit Cooperative Research Program (TRB TCRP)'s report *Synthesis 86: Relationships Between Streetcars and the Built Environment* defines the difference between streetcar and light rail as:

Streetcars are for local transportation. A Light Rail line may operate ten or 20 miles out beyond the downtown, running at high speeds between suburban stations spaced a mile or more apart. Streetcars operate in the downtown and perhaps a bit beyond it, picking people up and letting them off at almost every street corner. Often, people will use Light Rail to come into town, then use a streetcar to get around town.

Overall, streetcar is a form of light rail transit and can further be defined by a list of characteristics:

- is customizable, modern-looking and can feature branding;
- is operated by humans, as another user of the road, on a line of sight basis so can be responsive to changing conditions and surroundings;
- will stop to allow passengers to board and alight at stops/stations that are typically placed between 300 – 800 m apart;
- can operate at different speeds depending on the operating context;
- requires its own operations and maintenance facilities;
- features seated and standing capacity, as well as accessible areas for mobility aids and strollers;
- can include on-board areas for bicycles and luggage if required;
- can operate on a variety of track types, including:
    - tracks that are on tie and ballast;
    - tracks that can be embedded into hard- or green-surfaced areas; and
    - tracks that are directly fixed to hard surfaced areas, but are not embedded
- is typically propelled by electricity transmitted by wires, but is also capable of wireless propulsion;
- typically, does not exceed posted road speed limits when running integrated with or adjacent to traffic;
- can adapt to a variety of urban and suburban environments using speed, stop spacing and varying degrees of signalized prioritization;
- can adapt to a range of operating scenarios - full segregation to shared right-of-way on-street with other vehicles (including bicycles); and
- has similar scale stop infrastructure to a bus or BRT (B-Line).

2 Defining Streetcar in Vancouver

2.1 Historical Context

Streetcar was a common fixture in Metro Vancouver and the City of Vancouver between 1897 and the 1950s. The BC Electric Railway ran streetcar and interurban lanes in southwestern BC until the last interurban service was discontinued in 1958.

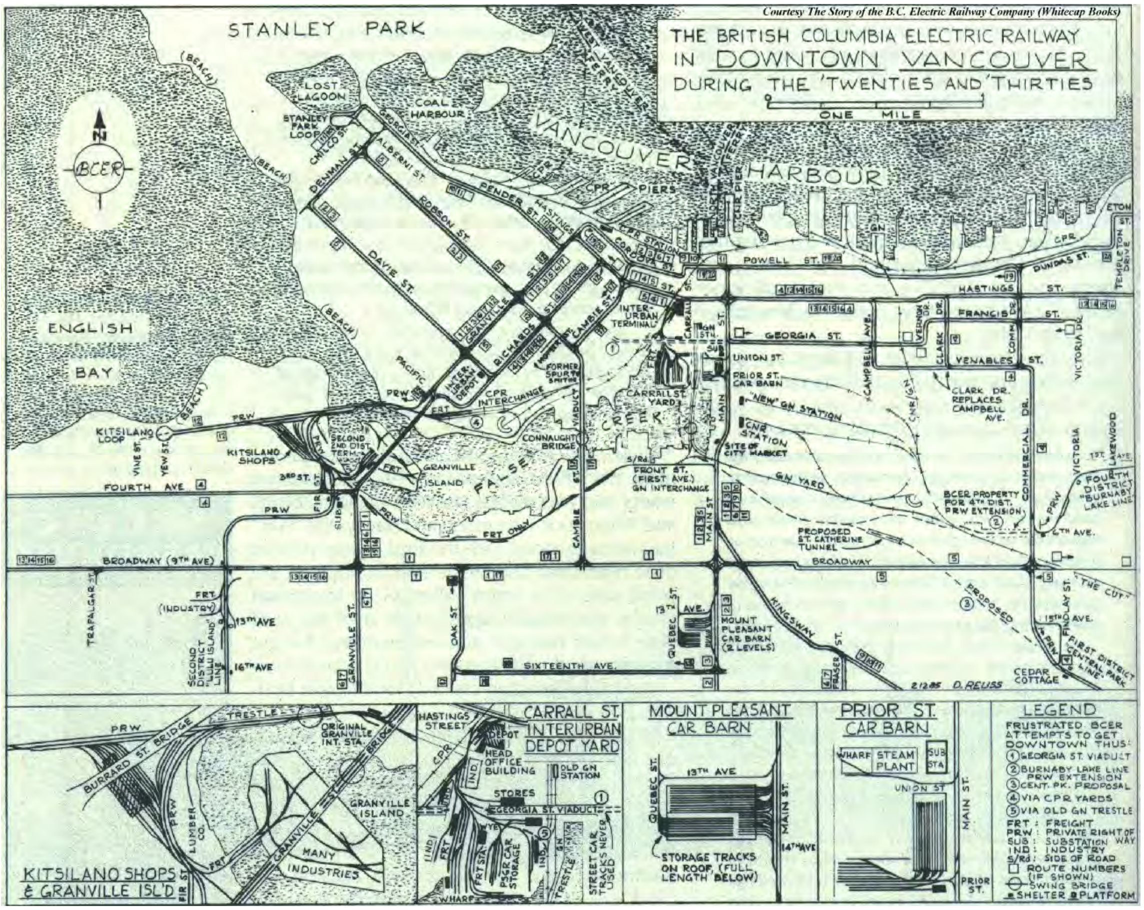

Figure 2-1 BCER Downtown Vancouver Map

The City of Vancouver began contemplating a reimagined streetcar in the mid-1990s when the City purchased a segment of former rail right-of-way between Granville Island and Cambie Street from CP Rail. This purchase of the 1.5 km False Creek South rail corridor occurred after BC Transit commissioned a study in 1991 for a streetcar system from Granville Island to Science World, and City of Vancouver commissioned a complementary study in 1994.

Then in 1997 the City pursued a study that assessed the options available for the streetcar's development. This study included the following vision statement for the streetcar:

- The Downtown Streetcar will be an alternative mode of transportation with similarities to the streetcar system that operated in the City earlier in the century
- Great Cities are about bringing people together; serving residents and visitors for both work and leisure

- The Downtown Streetcar will provide a service that links the downtown neighbourhoods, districts, services, and attractions
- The Downtown Streetcar will be a natural fit with the urban identity of Vancouver and will generate excitement, public involvement and commercial interest
- The Downtown Streetcar will allow for growth and evolution to respond to the Downtown's changing needs and new opportunities
- If these things are accomplished, getting around the Downtown will become easier and more enjoyable; a great benefit to all those who use our City

This vision statement continues to be relevant in today's context and the future context and will inform the imagined streetcar network and relevant studies.

The False Creek South rail corridor was utilized for the Downtown Historic Railway (DHR) in 1998. This demonstration was run by volunteers from the Transit Museum Society ("TRAMS") on weekends and holidays from May to October, and attracted considerable public interest. Thus, in 1999 a second historical car was added and in 2000 City Council voted to extend DHR to Science World and closer to the Main Street SkyTrain Station. The DHR continued to run through to 2011 as an excursion-oriented historic electric railway line, except for in 2010 when the line was used for the Olympic Demonstration Streetcar, a modern streetcar demonstration that supported the overarching transportation plan for moving athletes and people during the 2010 Winter Olympic Games in Vancouver. In 2012, DHR service was suspended indefinitely due to financial constraints.

Figure 2-2 BCER Interurban car 1207 on Downtown Historic Railway

In addition to running the DHR, the City has continued to take steps toward realizing a modern network via preserving right-of-way both on- and off- street, in several parts of the city, as development and street reconstruction has occurred. In 2000, the Arbutus Corridor Official Development Plan identified rail transit for the future Greenway. This led the City to purchase the Arbutus Corridor from CP Rail in 2016. The City's agreement with CP was intended to ensure that residents could continue to use the Arbutus Corridor as a sustainable greenway and transportation corridor, including walking, cycling and future streetcar – a clear link to the planning and policy foundation that had been laid to enable its revitalization. The Purchase Agreement specifies that portions of the corridor are to be planned for light rail use.

Additionally, the City has undertaken several studies for part or all of the proposed network. The wealth of previous work, which has been reviewed in 388583-MMD-00-P0-MO-TR-0001 – Background Document Review Memo (attached in Appendix A), forms the foundation for the development of the design guidelines presented in Section 1, which will be utilized during the Feasibility Study.

2.2 Policy Context

The City of Vancouver has had long-standing goals to redevelop a city-wide streetcar network. It aims to enrich its transportation network, further densify its urban core and midtown, and encourage more people to make the shift to sustainable modes.

This is exemplified by the City of Vancouver developing its Greenest City Action Plan in 2011, which lays the framework for Vancouver to become the greenest city in the world by 2020. A key component of achieving this goal is green transportation, which identifies walking, cycling and public transit as preferred transportation options. Green transportation can be achieved in several ways, including making active transportation choices comfortable and safe for people of all ages and abilities and increasing access to nature and green space.

In 2012, this led to the development and City Council approval of Transportation 2040, which is a long-term strategic vision for the city that will help guide transportation and land use decisions, and public investments. The plan is focused on promoting walking, cycling and transit, with the target to have at least two-thirds of all trips made by foot, bike, or transit by 2040. An interim target was also set to have at least half of all trips made by foot, bike or transit by 2020. This was similarly stated in the Greenest City Action Plan which had a target of the majority (over 50%) of trips by foot, bicycle, and public transit. The City proudly achieved this target in 2015.

Also in 2012, the City released its Healthy City Strategy: *A Healthy City for All*, a long-term integrated plan for healthier people, healthier places, and a healthier planet. The strategy builds on the transportation targets outlined in Transportation 2040 and recognizes opportunities to promote physical activity through many ways, including transportation. The strategy clearly outlines the connection between health and transportation and how making walking and cycling accessible for people of all ages and abilities can help encourage more physical activity.

In 2017, the Complete Streets Policy Framework was developed to help the City achieve its Transportation 2040 targets on mode share and safety for people of all ages and abilities. The framework builds upon the existing transportation policies while considering local context, connectivity and reliability of the broader transportation network, and a holistic street design for all modes of travel.

2.3 City-Shaping Context

The opportunity to reclaim, redevelop, and revitalize disused freight rail corridors as well as utilize futureproofed space within road rights-of-way of Vancouver's city core to create a world-class streetcar network is unique and important, not only from a multimodal transportation perspective, but in terms of its catalytic city-shaping potential.

Implementing integrated, context-responsive light rail transit in communities that are observed to be growing or ready to grow can enhance the aesthetic and function of public space, and can encourage mixed-use, sustainable development on a variety of scales.

TransLink's *Transit-Oriented Communities Design Guidelines* outline key attributes for creating more livable, sustainable, resilient and economically thriving places around transit in Metro Vancouver. The key principle is to concentrate growth in centres and corridors that are well-served by frequent transit.

Although the origins, destinations, and neighbourhoods surrounding the imagined streetcar network today are well-served by the Frequent Transit (bus) Network, enhancing transit passenger experience through the implementation of streetcar could increase transit ridership across Vancouver and within the neighbourhoods around the network. This will also complement and highlight the network benefits of the Millennium Line Broadway Extension on West Broadway, the Canada Line on Cambie Street, and the Expo Line into the downtown core via Main Street-Science World SkyTrain Station, Stadium-Chinatown SkyTrain Station and Waterfront Intermodal Station.

2.4 Network Routing History

Over time and through the various previous studies, the imagined downtown streetcar network has evolved and been refined. Routing maps from the 1990s looked to the historical British Columbia Electric Railway Company Limited streetcar network, which was phased out during the "Rails to Rubber" campaign in the 1940s and 1950s. From there it evolved as shown in the Background Review (in Appendix A) to the latest imagined streetcar network including a connection to the Arbutus Greenway as shown in Figure 2-3. This includes the strategic opportunity to stage the implementation of streetcar in more manageable components beginning with a 'Phase 0' section from Granville Island to Science World.

The work completed to-date on the envisioned streetcar network, in combination with Vancouver's original streetcar network, sets a firm foundation for where streetcar may be implemented. Next stages of network and corridor planning as part of the main Feasibility Study, as well as more specific route selection and confirmation of potential alignments, will be informed by the City's strategic planning processes as well as the technical considerations and recommendations made here.

Figure 2-3 Current Imagined Streetcar Routing

2.5 Local Studies

Overall there is a wealth of previous work on the imagined Vancouver Streetcar Network, particularly the Downtown Streetcar. This previous work will be used in this study and will reflect on Vancouver's original streetcar network to lay the foundation for the Feasibility Study. The background document review has highlighted the robust work over many years that has gone into the development and refinement of a modern Vancouver streetcar network, as well as the assumptions and parameters that need to be revisited and updated at this time. The following is a summary of the documents that as part of this scope of work have been reviewed; their key findings may be utilized going forward based on consideration and direction from the City.

Table 2-1 Background Document Review Summary

Document Name	Key Findings/Notes
PPP Review of Vancouver Streetcar Project ***(Macquarie North America, 2002)***	• Project could be delivered as PPP • Funding and operating arrangements to be made with government • Further analysis needed on ridership, project definition, phasing options, corridor selection and engineering specification
Downtown Streetcar Benchmarking Report ***(2004)***	• Extent of streetcar priority is important and most systems have some segregated running sections • New streetcar system platforms allow for universal accessibility • Stops are spaced further apart on dedicated alignments and closer together in downtown areas to maximize coverage • Peak services typically operate between 6 – 10 minute headways and off-peak services are generally half the frequency of peak periods • Healthy ridership levels are proportional to system size and transit coverage
Tourist and Recreational Usage of Proposed Downtown Streetcar ***(2004)***	• Streetcar fares and pricing should be integrated with the whole public transit network • The type of streetcar (modern versus historic styling) is not a key factor • Tourists and residents agree that the top destinations are Stanley Park and Granville Island, but there was more enthusiasm and commitment from tourists than residents about using the streetcar • Service frequency should be approximately 10-minute intervals or less

Document Name	Key Findings/Notes
Downtown Streetcar Design, Layout, and Ridership Study ***(IBI Group, 2005)***	• Preferred concept was: – segregated from traffic from Granville Island to Pacific Boulevard – a combination of segregation and mixed on-street traffic on Columbia Street – mixed with traffic east/west along Cordova Street and Water Street respectively
Streetcar and Local Bus Comparative Review ***(IBI, 2006)***	• Streetcars have higher initial capital costs than buses but this can be offset through additional ridership/passenger revenue and operating cost savings from integrated service • Streetcars with a dedicated right-of-way can run at higher average speeds, offer greater reliability and capacity than local buses in mixed traffic. • Streetcar has more presence than a bus route and can act as a redevelopment stimulus, as well as enhance urban design and streetscapes
Downtown Streetcar Project – Preliminary Design Report ***(Hatch Mott MacDonald, 2008)***	• Generic 2.46 m wide modern streetcar was used • Absolute minimum median of 7.1 m was recommended for 1st Avenue, with a maximum 8.4 m median/right-of-way (ROW)
Transportation 2040 ***(2012)***	• Advance a Downtown-False Creek-Arbutus streetcar service, through measures including: – protecting rights-of-way and designing streets to accommodate the service; and – working with TransLink on a business case
Northeast False Creek (NEFC) – Streetcar Considerations Memo ***(Mott MacDonald, 2016)***	• Outlined geometric parameters including: – Vehicle dimensions – Dynamic envelope – Roadway interfaces – Power supply • Provides high-level guidance on streetcar design for NEFC
NEFC – Streetcar Implementation Considerations Memo ***(WSP | MMM, 2017)***	• Provides high-level guidance and provide geometric parameters to be used as NEFC work progresses

Document Name	Key Findings/Notes
Arbutus Greenway Project (AGP) – Streetcar Planning & Context Memo ***(Mott MacDonald, 2017)***	• Will carry forward and build on: – A brief orientation to streetcar as a modern transit technology – The discussion of general design principles, including philosophical and technical considerations – Recommendations for streetcar design guidelines – Recommended geometric design parameters for streetcar and stops, and futureproofing rights-of-way with these parameters in mind

2.6 Local Regulations

Given the scarcity of at-grade modern streetcar systems (Toronto's introduction of new vehicles is an exception as it is an existing system) currently operating in Canada, and particularly in British Columbia, there is a shortage of definitive design parameters or regulatory literature regarding Canadian operations. Although streetcar design parameters are not significantly varied throughout the world, there are unique regulatory considerations dependent on location and operating context; for instance, regulatory requirements may differ between highly urbanized and more natural environments.

The only regulatory literature for at-grade rail systems currently applied in British Columbia is for freight rail or commuter rail (West Coast Express) – both technologies whose operating characteristics are markedly different from streetcar.

However, there are several Canadian modern at-grade light rail systems that are in the design and construction phases or are moving towards operation. One such project is TransLink's South of Fraser Rapid Transit Project, which will be the province's first modern at-grade light rail system. TransLink is currently involved in discussions around operations with provincial authorities, so the outcomes for the Surrey LRT project may be applicable to the Vancouver streetcar network in the future.

The upcoming feasibility study will not resolve these issues but recommendations made will be based upon emerging precedents as they become available.

2.7 Industry Technical Guidance

Industry standards and guidelines for modern streetcars are well-established across the globe, and vary in applicability based on geography and operating characteristics. Technical documents which are well-suited to inform planning and design work for the Vancouver Streetcar Network include but are not limited to:

- *Transit Cooperative Research Program (TCRP) Report 155: Track Design Handbook for Light Rail Transit* – is based upon historic and current practices for many light rail projects across North America. It sets out principles and parameters which are adopted as industry standards by designers when developing rail based transit systems.
- *Guidance on Tramways, Railway Safety Publication 2 (RSP2), Office of Rail Regulation* – is a guideline published by the UK's regulatory body for railways which has oversight for safety on tramways. It provides useful additional guidance over what is included in the TCRP report, particularly around how these types of systems interact with road traffic, pedestrians, and cyclists.
- *APTA RT-ST-GL-001-13: Modern Streetcar Vehicle Guideline* – provides typical parameters and capabilities for streetcars and some discussion about how they interact with and influence other aspects of a system's design.
- *APTA SUDS-RP-UD-005-12: Design of On-street Transit Stops and Access from Surrounding Areas* – discusses ways to provide or improve connections to, from and at on-street transit stops, regardless of mode
- *National Association of City Transportation Officials' (NACTO) Design Guides* - NACTO has published four design guides that provide useful context for this study – Urban Street Design Guide, Global Street Design Guide, Urban Bikeway Design Guide and Transit Street Design Guide. Each provides an overview of best practices for planning and design of safe and inviting streets in an urban context.
- *Manual on Uniform Traffic Control Devices for Streets and Highways 2009 Edition (Revs 1 and 2) published by the U.S. Department of Transportation* – Part 8 describes the traffic control devices that are used at grade crossings where light rail transit (which includes streetcars) interact with vehicular traffic.
- *Universal Accessibility Literature and Guidelines* – while there is not one formal resource for universally accessible planning and design in Canada, several resources can inform design approaches:
  - *Americans with Disabilities Act (ADA)*
  - *Rail Vehicle Accessibility Regulations (RVAR)*
  - *TransLink's Accessible Bus Stop Design Guidelines (via Pilot Project)*
  - *7 Principles of Universal Design*

  Elements of these technical documents will be referenced throughout the Best Practice Section.

2.8 Design Approach

2.8.1 Universal Accessibility

Vancouver is showing leadership in inclusion in city-building, considering a holistic approach with universal accessibility not as an afterthought, but as a *given* in planning and design.

While it is true that designing with an accessibility lens prompts careful consideration of "typical" or "standard" elements, it is also true that innovations in technology, paired with the application of basic principles, can result in a system that is inherently universally accessible rather than one that is retrofitted or partially accessible. Universal accessibility is considered a "given" in this discussion, and considerations are reflected in pedestrian sections. General design principles follow.

"Accessibility" no longer refers to a narrow scope of remedies for people with mobility impairments. Accessible design is the application of universal design principles that improve the safety, convenience, and usability levels for all users. This includes people experiencing a range of physical and cognitive conditions, which may necessitate that design go beyond minimum standards or existing regulatory requirements. The considerations presented are informed by the 7 Principles of Universal Design, and demonstrate that accessibility measures can be beautiful, safe, and cost effective.

Table 2-2 The 7 Principles of Universal Design

	Principle	Comment
1	Equitable Use - The design is useful and marketable to people with diverse abilities.	This can be realized by undertaking the design and implementation of the city-wide streetcar network in a way that aligns with these principles.
2	Flexibility in Use - The design accommodates a wide range of individual preferences and abilities.	This could include considering passengers' pace entering the streetcar vehicle when setting dwell times at stops, or designing stop and vehicle elements ambidextrously and with clear lines of sight (not only in the periphery).
3	Simple and Intuitive Use - Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.	This will be realized through effective wayfinding and visual and audible cues for passengers.
4	Perceptible Information - The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.	This is of importance when considering information hierarchy and safety for all users; maximizing legibility of essential information and prioritizing information not only visually but also using sound and tactility.
5	Tolerance for Error - The design minimizes hazards and the adverse consequences of accidental or unintended actions	Principle 5 is also tied closely to safety, particularly for a street-running streetcar system with minimal or no physical segregation. The design should strike the balance between providing a tolerance for error – reflected in the numerous failsafes and buffers in the technical guidelines in Section 3.1.1.4 – and not compromising the operational efficiency of the system. One such example is ensuring any trackway intrusion management systems are calibrated to a reasonable sensitivity (i.e. recognizing the difference between a human versus a leaf or plastic bag).
6	Low Physical Effort - The design can be used efficiently and comfortably and with a minimum of fatigue.	In planning and designing Stop accesses and for overall system use (fare vending, grades, scale of infrastructure, maintenance detours), the City should adopt a "lowest and slowest" approach; those lowest to the ground (i.e. children, people in mobility aid devices) and who travel more slowly than average users (i.e. anyone of any age with reduced mobility, whether temporary or permanent) should be easily accommodated and able to use the system with relatively little physical effort.

	Principle	Comment
7	Size and Space for Approach and Use - Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.	This Principle asks the designer to consider not only the space required to accommodate mobility aid devices, but also to consider motor function abilities. For example, designing safety phones and door handles that those who cannot physically grasp or squeeze can still use these elements.

Universal Design considerations should inform the development of the wider network, and can also guide the design of specific components of the system.

Lessons Learned: It is best to apply a universal design lens throughout the design process rather than audit, retrofit, or apply it in part later.

2.8.2 Walking

Integration with existing multimodal infrastructure, and in particular with pedestrian infrastructure, is a key success factor of a line or whole streetcar network. It is true that every transit trip begins and ends with a walk trip, so enabling seamless transitions between these two modes – through ambient infrastructure and through pedestrian access to streetcar stops - is critical in promoting safety, efficiency, and attractiveness.

Light rail systems in urban environments generally have a walkshed – a radius of walkable area – of about 400 – 800 m, or up to 1 km, so providing walking connections within this range will improve safety, accessibility, and attractiveness of a streetcar system.

Figure 2-4 Five-Minute Walkshed along Frequent Transit Service
(credit: TransLink Managing the Transit Network)

Context-specific design guidance for pedestrians is discussed throughout the document.

2.8.3 Cycling

In general, cycling and streetcar facilities can coexist, but safety and efficiency for each mode is improved when they are segregated. Specific guidance is discussed throughout the document, drawn from NACTO and based on local and international experience.

3 Planning & Design Considerations

While it is true that streetcar and its ancillary infrastructure have specific and generally inflexible geometric requirements, innovations in technology and context-sensitive design have significantly improved the extent to which streetcar can be integrated into urban environments.

This report provides a review of the physical requirements of a streetcar system and ancillary infrastructure. The physical requirements, best practices in design, and design standards for streetcar and other relevant elements of a streetscape in Vancouver's context are then presented. This approach provides a holistic, integrated, and multimodal view of implementing streetcar into Vancouver's existing urban context.

3.1 Streetcar Spatial Requirements

The streetcar and its track geometry typically impose the most constraints on the development of a streetcar system. The following sections outline the typical space streetcar vehicles require, which is based on vehicle type and size, and the track geometry it uses to navigate through the city.

There are also other streetcar related infrastructure and considerations that have spatial requirements, but these are less rigid. These ancillary streetcar considerations are discussed in Section 4.

3.1.1 Vehicles

There is a wide variety of streetcar vehicles available today. Manufacturers can create a streetcar vehicle to many diverse specifications for overall look and feel, size, and level of universal accessibility. Propulsion systems and a myriad of other operational and physical features can be adjusted to suit client requirements. As cities expand their transit networks and densify their urban areas, there is an increasing appetite for and supply of urban-style, low-floor light rail transit or streetcar vehicles. Additionally, manufacturers have a growing ability to deliver vehicles that are responsive to constrained urban contexts; a wide variety of widths, lengths, and maneuvering capabilities can be supplied. Nevertheless, choosing the standard vehicle dimensions and options will always provide the most cost-effective solutions and assist in future proofing the system design by avoiding bespoke vehicles.

In Canada, there are few policies and regulations that restrict suppliers, and therefore the options for the procurement of streetcar vehicles and the number of potential suppliers available is large compared to the US where 'buy America' policies are in effect.

Figure 3-1 European style LRVs from Birmingham (CAF) and Nottingham (Bombardier)

Figure 3-2 US Streetcars from Salt Lake City (Siemens) and Portland (Skoda Inekon)

3.1.1.1 Vehicle Layout

Modern streetcars are generally manufactured in High Floor, Partial Low Floor or Full Low Floor configurations. Partial Low Floor and Full Low Floor vehicles are usually favoured for use on in-street running systems due to the reduced visual and operational impact of the infrastructure required (i.e. low passenger platform heights and step-free boarding).

Many modern LRVs and streetcars can be acquired with on-board energy systems to avoid the need for over head power supply. This is addressed further in Section 4.6.4.

Partial Low Floor Vehicles

Part Low Floor vehicles generally use a combination of conventional axle wheel-sets on pivoting bogies (also known as trucks) and fixed trailer bogies with independently pivoting wheels to provide low-floor access. They are usually rated for a maximum operational speed of 80 km/h. This arrangement allows the vehicle to maintain a low platform/entrance height but still have reasonable ride and performance characteristics.

Floors are raised in sections (accessed via steps) to accommodate the motor bogies, typically 500 – 900 mm above rail level in these areas, while the lower floor area will be between 300 – 400 mm. Typically, these vehicles have a low floor area of between 50% and 80% of the passenger interior area as depicted in Figure 3-3 and Figure 3-4.

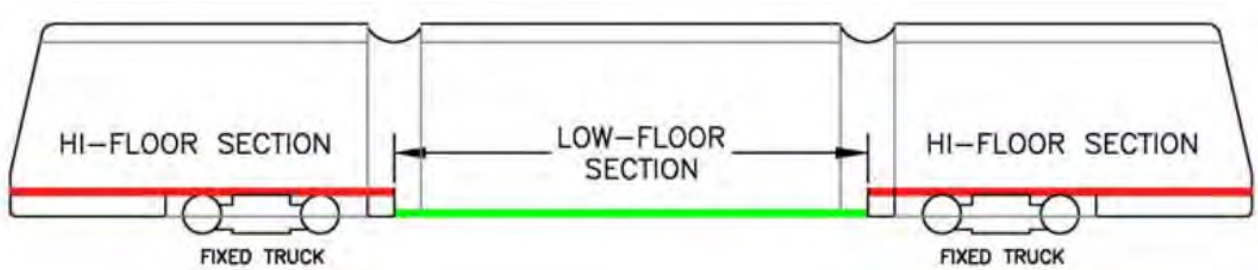

Figure 3-3 Three-Section 50 Percent Low-Floor Vehicle
(credit: APTA RT-ST-GL-001-13)

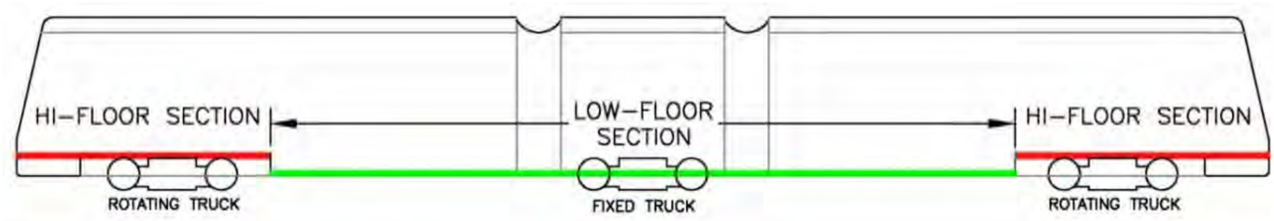

Figure 3-4 Three-Section 70 Percent Low-Floor Vehicle
(credit: APTA RT-ST-GL-001-13)

The illustration below shows the raised floor section within the passenger interior typical of a Part Low Floor vehicle.

Figure 3-5 Raised Floor Section in Partial Low Floor Vehicle

Typically, manufacturers offer these vehicles to a standard specification in terms of length. Experience has shown that the high floor areas can become under utilised with passengers generally congregating around the doorways and low floor areas.

The low floor areas of the vehicle are used to accommodate the doors for step-free passenger access, and the low door threshold height means the platforms required are less intrusive on the surrounding environment than those used for High Floor vehicles.

Full Low Floor Vehicles

As the term suggests, Full Low Floor or 100% Low Floor vehicles have a continuous floor height above rail level of between 275 – 400 mm. These types of vehicles are usually made up of a number of modules, typically 5 modules for a nominal 30 m long vehicle and 7 modules for a nominal 40 m long vehicle. Motors are usually mounted on the outside of the bogie frames, allowing the low-floor to pass over the bogie without the need for steps.

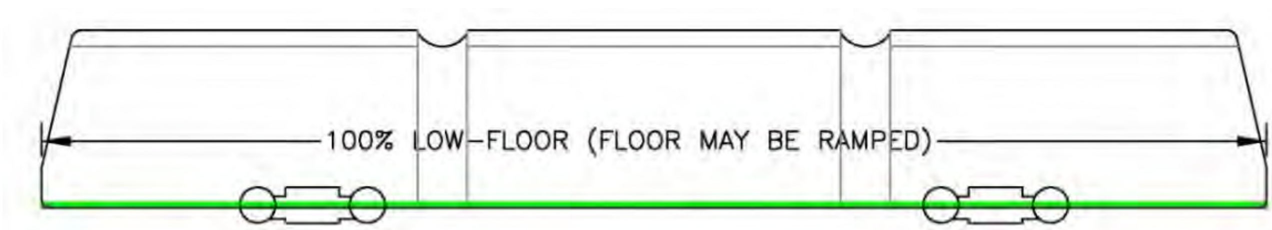

Figure 3-6 Multi-Section 100 Percent Low-Floor Vehicle
(credit: APTA RT-ST-GL-001-13)

The illustration below shows the passenger area of a typical Full Low Floor vehicle.

Figure 3-7 Inside of 100% Low Floor Vehicle

Modern variants of Full Low Floor have developed to maintain a step-free interior space, whilst still achieving many of the performance benefits that Partial Low Floor vehicles have, however, for some models ride quality and performance may be reduced.

The modular construction of Full Low Floor vehicles makes them very flexible in terms of vehicle length through the introduction of additional intermediate modules. It is even possible to increase their length at a later point in time.

One disadvantage of the modular design is the multiple articulations as this can lead to generally higher internal noise levels than their Part Low Floor counterparts.

Most full low floor vehicles have a maximum speed of 70 km/h, as they are typically used on true street running systems where higher running speeds are not required. Some suppliers are reluctant to provide these vehicles with a higher speed capability, such as 80 km/h, due to the costs associated with redesigning the drive system and making the vehicle more stable at higher speeds.

Full Low Floor vehicles are generally more aesthetically pleasing and as such make this design a popular choice in many cities that are concerned with the visual effects that the installation of a street running light rail scheme can have on the existing city realm and infrastructure. This type of vehicle also provides improved accessibility throughout the passenger interior due to the lack of internal steps.

Recommendation: In the case of the Vancouver streetcar, an urban-style, full low-floor streetcar is likely the most appropriate to achieve the City's universal accessibility objectives. This is not to say that the overall look and feel of the streetcar must be modern; a heritage design that offers these benefits can be procured but usually at a cost premium because of their bespoke nature, as most suppliers would prefer to offer their latest standard models.

Given that the streetcar is not envisaged to be implemented in the near term, it is likely that light rail / streetcar vehicle technology will continue to advance, increasing vehicle type options.

Based on a standard generic full low floor vehicle, the key parameters that are likely to influence alignment and infrastructure designs are tabulated below.

Table 3-1 Vehicle Parameters

Parameter	Proposed Criteria	Comments
Streetcar Length	30 m	Nominal 30 m length. Note 30 m is a nominal value, some model variants may be longer (e.g. 32.8 m). Northeast False Creek (NEFC) and Arbutus Greenway Project (AGP) assumed 35 m platform lengths
Streetcar Height	3.3 – 3.8 m	Range from Top of Rail to top of roof
Streetcar Width	2.65 m	Overall body width, excluding external mounted mirrors or cameras Standard width for vehicles supplied by most manufacturers. 2.4 m vehicles are also common but impose capacity constraints
Vehicle Width at door threshold	2.65 m	Will define platform edge requirements. Note: Width at door threshold height is likely to vary between vehicle models
Door Threshold Height	350 mm	Indicative door threshold height based on a 300 mm platform height and a +/- 50 mm LRV door threshold height
Typical Operating Speed	30 – 50 km/h	Design speed of the streetcar will generally depend on the road classification, adjacent parking lanes, proximity to parks and school, and sightline issues. This will be further analyzed as the project progresses.
Maximum Design Speed	70 km/h	Many manufacturers will supply vehicles capable 80 km/h or higher May be a requirement for 80 km/h in order to future proof the vehicles for future extensions to the system

3.1.1.2 Dynamic Envelope

The dynamic envelope is the space which the streetcar can theoretically occupy. It is a function of the cross-sectional dimensions of streetcars and their loads. It allows for tolerances in the manufacture of the streetcars and the effects on the suspension of passenger and wind loading while on straight and level track. This is then enlarged to allow for the maximum possible displacement of the streetcar in motion.

Consideration is also needed for the tolerances in track construction and the effects of track wear or maintenance. These allowances, when added to the vehicle's dynamic envelope, is often referred to as the kinematic envelope.

VEHICLE DYNAMIC ENVELOPE (OFFSETS FROM CENTERLINE AND TOR) FOR POINTS ON CAR (mm)										
OUTSIDE CURVE	B1	M1	M2	B2	B3	B4	P1	P2	P7	P8
20 m radius										
Horizontal	1490	1780	1800	1595	1410	1330	1125	9300	1245	1050
Vertical	205	2145	2675	2840	3256	3500	3750	3990	6040	6275
Tangent										
Horizontal	1310	1575	1595	1420	1300	1215	1125	9300	1245	1050
Vertical	205	2145	2675	2840	3255	3500	3750	3990	6040	6275
INSIDE CURVE	B1	M1	M2	B2	B3	B4	P1	P2	P7	P8
20 m radius										
Horizontal	-1570	-1650	-1670	-1680	-1560	-1475	-1125	-930	-1245	-1050
Vertical	205	2145	2675	2840	3255	3500	3750	3990	6040	6275
Tangent										
Horizontal	-1310	-1575	-1595	-1420	-1300	-1215	-1125	-930	-1245	-1050
Vertical	205	2145	2675	2840	3255	3500	3750	3990	6040	6275

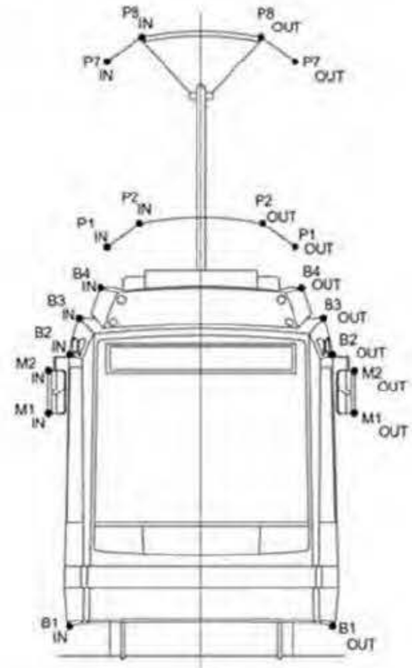

Figure 3-8 Typical Dimensions for a U.S. Streetcar's Dynamic Envelope

These representative dimensions and parameters are typical of US streetcar vehicles; however actual values will vary between different vehicle models.

3.1.1.3 Swept Envelope

The section above describes a rail vehicle's movement envelope under dynamic conditions on a straight track. This envelope is further expanded when the vehicle negotiates a curved section of track. The distance that the vehicle protrudes to the outside of a curve, typically at its nose, is known as end-throw or out-swing. The distance that the vehicle cuts to the inside of a curve, typically at the middle of a module is known as centre-throw or in-swing. These distances can be significant and are influenced by the car/module lengths as well as the bogie, wheelset and articulated joint spacings/positions along the length of the vehicle.

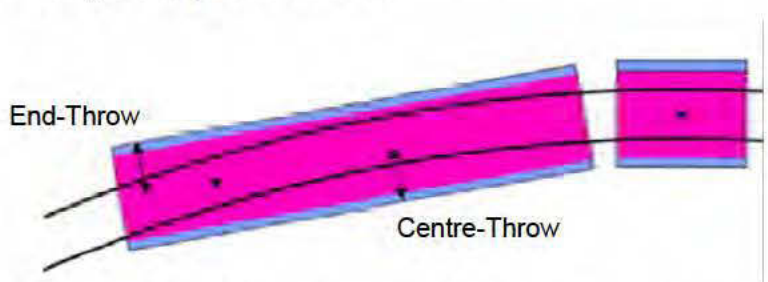

Figure 3-9 - Illustration of end-throw and centre throw

The swept envelope is developed from the dynamic envelope and it takes into account the effects of track curvature, including superelevation, and end- and centre-throw of the streetcar. It is speed dependent, and is unique to each vehicle and each particular location at a given speed.

Simplified methods of estimating these envelopes will be used in the Feasibility Study; however, due to the complexity of developing these envelopes, later stages of development should define the requirements in more detail so as not to restrict the procurement of vehicles in the future.

Recommendations:

At this stage of project development, it is best to make reasonably conservative allowances for the space requirements. Further assessment of the requirements on curves will be set out in the Feasibility Study.

Table 3-2 Streetcar Swept Envelope Parameters

Parameter	Proposed Criteria	Comments
Swept Envelope (SE) Width – Straight Track	3.3 m	Considered a conservative assumption that allows for a range of vehicles and some shallower curves without additional widening
Swept Envelope (SE) Width – Curved Track	Varies	Depending on the radius of curve a minimum in-swing and out-swing will need to be accounted for. The effect of superelevation will need to be considered on the inside of curves. For simplicity, the effects can be assumed to add twice the applied superelevation to the in-swing of the vehicle (e.g. for a rail superelevation of 50 mm, 100 mm would be added to the in-swing of the swept envelope).

3.1.1.4 Clearances

It is necessary to provide additional clearances beyond the vehicles' swept envelop in order to provide a safe streetscape for all users. From TCRP and other industry best practices, the following are recommended clearances to be used in the streetcar design:

Table 3-3 Clearance Parameters

Parameter	Proposed Criteria	Comments
Between two streetcars DEs without centre OCS poles	200 mm	TCRP 155
Between two streetcars DEs with centre OCS poles	800 mm With at least 150 mm to the face of the pole	Most poles will typically be less than 500 mm but occasional ones may need to be larger
Centreline track to edge of platform	1375 mm	Typical distance for a 2.65 m wide vehicle.
Isolated Obstruction – Clearance to Swept Envelope	600 mm preferred 100 mm absolute	The absolute minimum should only be considered in locations where streetcar is segregated and pedestrian access is restricted
Continuous Obstruction –	1000 mm preferred 600 mm absolute	This will be further analyzed as the alignment adjacencies and conflicts are investigated.

Parameter	Proposed Criteria	Comments
Clearance to Swept Envelope		
Edge of pedestrian walkway or bicycle pathway – Clearance to Swept Envelope	600 mm preferred 400 mm absolute	This will be further analyzed as the alignment adjacencies and conflicts are investigated.
Shyway from streetcar SE to adjacent traffic if segregated	300 mm	Minimum width of curb and cutter
Distance to edge of traffic lane if shared running	100 mm	Allowance to avoid any conflicts between streetcar SE and vehicle in adjacent lane

3.1.1.5 Vehicle Ancillary Considerations

Corridor Intrusion Detection

Corridor intrusion detection is a feature on the current Vancouver SkyTrain system to detect for possible intrusion by persons or objects entering the track areas within the likes of stations. This is an important feature for the SkyTrain system as it uses driverless automatic trains. For the proposed Vancouver Streetcar system this feature would not be required because the vehicles will have drivers using a line of sight mode of operation similar to a bus or other road vehicle. This particular detection system would also not be practicable in an urban environment where pedestrians and other road users exist.

Collison Protection Technology

The automotive industry is currently leading in collision detection technology with many suppliers offering different levels of detection as standard features or optional extras. Many of these features are transferable to rail applications, especially for streetcar applications. The rail industry is now starting to reap the rewards of the technologies from automotive research & development (R&D) work, as some rolling stock suppliers are already considering and adapting these features for their streetcar applications. For example, Bombardier is working closely with Bosch looking at active and passive safety technology for the driver and passengers.

The Bosch system provides a forward collision warning system for light rail vehicles which uses on-board radar and video sensors. The aim of these electronic systems is to increase passenger/pedestrian safety while unburdening rail vehicle drivers by applying automotive sensor expertise to rail vehicles. While the application of this technology to rail vehicles is still under development, prototypes are being put through their paces using Bombardier streetcar vehicles in Frankfurt and Hannover. It is expected that the technology will be seen on in-service vehicles in the coming years and may well become an industry standard by the time Vancouver's streetcar network is realised.

Automatic Speed Control

Automatic speed control is not new in rail vehicle applications and in many cases, comes as a standard feature. Examples include over-speed protection where the vehicle propulsion is disabled once the vehicle reaches a certain speed and brakes are applied if an even higher speed is achieved. Even greater control can be achieved with an Automatic Train Protection (ATP) system which continually checks that the speed of a train is compatible with the permitted speed allowed by signalling. If it is not, ATP activates an alarm and a brake is applied if the driver doesn't respond within a few seconds. As such automatic speed control is typically down to the customer requirements and should be clearly laid out within the vehicle technical specification.

It could be included as a requirement on streetcar vehicles to prevent overspeed into curves although it would not assist drivers in matching the speed of road traffic in in-street shared running alignments.

3.1.2 Track Geometry

Track geometry allows for the streetcar to safely navigate its environment while ensuring passenger comfort, and the vehicles and track perform well together. It is governed by multiple factors including:

- Physical space restrictions
- Vehicle capabilities
- Passenger comfort
- Maintenance considerations
- Noise and vibration considerations
- Construction
- Track type

3.1.2.1 Horizontal

The horizontal geometry of track consists of tangents and circular curves normally connected via spiral transitions to eliminate sudden change of direction. Applying superelevation where possible maximizes operating speeds while enhancing passenger comfort and helping to reduce rail wear.

Generally, horizontal geometry is governed by physical restrictions and minimum operating performance requirements.

Larger radii curves are preferred as tighter curves have increased noise and wear and reduce speeds. However, in a dense urban environment, trade-offs often need to be balanced between track geometry and other corridor elements to optimize the complete streetscape.

The following are the recommended horizontal geometry design parameters.

Table 3-4 Horizontal Geometry Design Parameters

Parameter	Proposed Criteria	Comments
Absolute Minimum Horizontal Curve Radius	25 m absolute	Although it may be possible to acquire vehicles capable of tighter radii, 25 m is considered achievable by most modern streetcars. Note: some modern streetcars can negotiate 18 m radius curves.
Desirable Minimum Horizontal Curve Radius	150 m	Reduced speed required with radii less than 150 m. Upper range on minimums preserves for larger range of streetcar technologies
Length of horizontal curves	Greater of 0.57 V or 15 m	The design requirements are speed dependent and should be optimized based on the vehicle performance and the attainable operating speed. V = design speed, km/h

Parameter	Proposed Criteria	Comments
Desirable minimum length of spiral transition	20 m	
Absolute minimum length of spiral transition	10 m	
Desirable minimum length of tangent between reverse spiral curves and reverse circular curves	Greater of 0.57 V or 15 m	The design requirements are speed dependent and should be optimized based on the vehicle performance and the attainable operating speed. V = design speed, km/h
Absolute minimum length of tangent between reverse spiral curves	0 m	The spiral curves and the curve radii are in a desirable range to minimize the twisting effect induced to the coupler of the vehicle. This is not good practice and should not be used unless it can be justified

3.1.2.2 Vertical

Vertical track geometry is made up of constant grade tangents connected at their vertical intersection by parabolic curves, sag or crest. Generally, the following sections outline industry best practice for vertical grades.

TCRP Report 155: Track Design Handbook for Light Rail Transit

Section 3.3.2 of TRCP 155 outlines recommended vertical grades and notes that maximum track grades are dictated by vehicle braking and tractive capabilities. Table 3.3.1 of TCRP 155 provides general guidelines for maximum gradients on mainline tracks as follows:

Table 3-5 TCRP 155 Table 3.3.1

Desired Maximum Unlimited Sustained Grade (any length)	4.0%
Desired Maximum Limited Sustained Grade (up to 2500 feet [750 meters] between points of vertical intersection (PVIs) of vertical curves)	6.0%
Desired Maximum Short Sustained Grade (no more than 500 feet [150 meters] between PVIs of vertical curves)	7.0%
Absolute Maximum Grade Unless Restricted by the Vehicle Design (acceptable length to be confirmed with vehicle designers)	9.0%
Acceptable Minimum Grade for Drainage on Embedded Track	0.5%
Acceptable Minimum Grade for Direct Fixation and Ballasted Trackforms (provided other measures are taken to ensure drainage of the trackway)	0.0%

Pocket tracks are typically flatter grades as they can serve as temporary storage tracks. Whereas yard tracks or long-term storage tracks are to be as flat as possible or sloped downward away from the mainline to avoid vehicles rolling away and onto the mainline.

APTA RT-ST-GL-0001-13: Modern Streetcar Vehicle Guideline

APTA RT-ST-GL-0001-13 emphasizes that electrically powered transit vehicles can climb and descend steep grades, but notes that the vehicles require specific propulsion and braking systems capabilities and that there are trade-offs with vehicle cost, operational speed and long-term maintenance. It references Table 3.3.1 from TCRP 155 for typical grade limits.

It also identifies that sustained gradient over 9% are problematic but there are a number of systems which currently operate on 10% gradients, such as Pittsburgh's Brown Line which is now operated only occasionally due to service cuts.

Market Research

Previous market research conducted for the Arbutus Greenway Project has shown that most LRV and streetcar manufacturers will supply vehicles capable of 8% gradients, with very few existing systems that operate on grades in excess of 10%. The one example of a system with a maximum operating grade in excess of 10% is Pöstlingbergbahn in Linz, Austria. This system has a narrow gauge of 900 mm, and being able to acquire the same vehicle type with similar performance specifications here in Canada is uncertain. There are two systems that have a maximum grade of 10%, one being the Supertram in Sheffield, UK which uses a bespoke vehicle. The Brown Line in Pittsburgh also has a maximum grade of 10%, and is a high floor system and its regular service has been withdrawn on this line due to funding cuts.

The vehicle supplier investigation for Arbutus Greenway Project concluded that there are several vehicle suppliers that may supply a streetcar capable of negotiating a 10.5% gradient. However, the requirement would restrict the number of suppliers available, which could result in a less competitive procurement process. The limited size of the potential order may also deter other suppliers, especially considering the up-front costs to modify the vehicles since there is not a great demand for vehicles that are capable of negotiating a 10.5% gradient. Nevertheless, the investigation showed that it is likely to be a feasible option at an increased cost if regrading is not desired.

Based on investigation of the Vancouver context and potential streetcar corridors, industry best practices, and market research, the following table outlines the recommended vertical geometry design parameters.

Table 3-6 Vertical geometry Design Parameters

Parameter	Proposed Criteria	Comments
Maximum gradient	6% preferred 10% absolute	6% is recommended in TCRP 155 but previous market research and project experience has shown that manufacturers will supply vehicles capable of 8% gradients. APTAs Modern Streetcar identified that sustained gradient over 9% are problematic but there are many systems which currently operate on 10% gradients. And as noted, vehicles capable of 10% or higher will likely come with an increased cost
Minimum vertical curve radius	K = 5 (500m)	The "K" value defines the rate of change in vertical curves for parabolic curves Typical parameters adopted by other systems
Desirable minimum vertical curve radius in areas of superelevation gradient	K = 20 (2000 m)	

Parameter	Proposed Criteria	Comments
Absolute minimum length of vertical crest curves	Greater of 0.57 V or 15 m or $AV^2/215$	A = the algebraic difference of the connected gradients, in percentages V = design speed, km/h
Absolute minimum length of vertical sag curves	Greater of 0.57 V or 15 m or $AV^2/387$	A = the algebraic difference of the connected gradients, in percentages V = design speed, km/h
Minimum length of vertical grades	Greater of 0.57 V or 15 m	

With this summary of recommendations for geometric minimums required for streetcar in Vancouver, we can now consider the integration of streetcar into the existing urban fabric of the city.

3.2 Integrating Streetcar in Vancouver: An Urban Context with Multiple Modes

The City of Vancouver has seen great success in developing its existing multimodal transportation network, experiencing a steady increase in mode share of transit, cycling, and walking in recent years. Vancouver is home to continuously-evolving streets that are effective multimodal transportation corridors and beautiful, safe, great places for people. Different to other contexts, nonmotorized modes are often given priority over motorized modes – not just in policy, but also in the physical context.

In addition, the City is keen to develop a streetcar system that functions as an efficient form of transit, and is part of the wider transit network.

Balancing these priorities – ease of use for nonmotorized modes, creating great streets as places for people, and propagating streetcar as an efficient transit technology – can be achieved, so long as an agreed and definitive approach is taken, and context-sensitive integration is enabled. This is to say that it is not always possible to maximize the *efficiency* of one mode without endangering the safety, experience, or functionality of another mode. Sensitive integration of streetcar into this environment will require consideration of Vancouver's overall city priorities in partnership with what it hopes to achieve with streetcar.

The City of Vancouver's Transportation 2040 identifies its mode hierarchy as:

1. Walking
2. Cycling
3. Transit
4. Taxi / Commercial Transit / Shared Vehicles
5. Private Automobiles

This hierarchy can be applied in general terms, and can be adjusted slightly to respond to different physical and operational contexts across modes. This may be particularly true across *types* of transit – ranging from rapid to slower transit vehicles, and ranging across levels of physical segregation – and the diversity in their relationships to other modes.

For example, physical and operational integration between a relatively slow-moving streetcar (classed as transit in the Transportation 2040 hierarchy) and pedestrians and cyclists will be markedly different than between a rapid bus or light rail vehicle and active modes.

Levels of priority and segregation can and should be adjusted to promote efficiency, safety, and accessibility across all modes. What works in one corridor or section may not be appropriate in another context, so the City should be prepared to prioritize different modes and street users in different contexts. It is worth reiterating that the style of streetcar transit envisioned for Vancouver would be operated by a driver using line-of-sight operation and braking capability. This is different to the automated, grade-separated SkyTrain system that pervades the local context. The difference means that the City can utilize lighter levels of physical segregation, and can mix priority across modes in different parts of Vancouver.

If streetcar priority over all other road users is desired, this can be achieved through physical segregation and/or signalization technology, and can be applied throughout a route and/or at intersections. As above, a sliding scale approach can be taken in different contexts, and should be applied to achieve different goals.

In the next sections, we first discuss geometric priority, and in the next section, signal priority, for streetcar. We also discuss planning and design considerations across these bands of priority for other road users.

3.2.1 Priority through Geometry

There are various levels of segregation that can be provided for streetcar when it operates in an urban and suburban environment, such as Vancouver. The following section outlines different levels of segregation and their operations considerations, ranging from least segregated to most segregated.

3.2.1.1 In-Street Shared Running

In-street shared running streetcar schemes are appropriate in constrained corridors where streetcar is not required to operate quickly, or on streets where overall calming and slower speeds by all modes are accepted and desired. On-time, reliable performance can be affected when a right-of-way is shared, due to a lack of predictability and vulnerability to obstructions and disruptions.

Streetcars can integrate with road traffic to make use of limited available road space, just as buses do in Vancouver today with the use of bus-only lanes. One example is on Lameys Mill Road in the South False Creek Area, where a bus only lane is accommodated through the constrained Alder Crossing intersection, preventing through traffic and therefore reducing overall traffic on the street.

Where necessary to operate within busier streets, it is important to ensure the mode hierarchy is clear and legible for all road users, using signalization, signage, and pavement markings.

In general, shared-use tracks placed within active streets are more disruptive, difficult, and expensive to maintain.

Streetcar priority can also be managed with shared trackways using traffic signalling to provide full and/or partial priority at traffic signals. This is further described in Section 3.2.2.

Centre Running

This alignment generally follows the centre traffic lanes within a street. Stop platforms can be constructed between the two streetcar tracks in what would effectively be a centre median space. It will typically allow for the most consistent track location within the street right-of-way (ROW) as it does not have to shift for right-turn lanes. Additionally, it has the potential to have a flatter rail cross level due the parabolic crown in road, and less debris and water is directed across the tracks.

Split Curb Running

This alignment generally follows the curb traffic lanes within a street. The streetcar could be either immediately adjacent to the curb and pedestrian realm or offset from the curb by a parking lane and/or bike lane. This alignment can have operations similar to bus operations but can be impacted by vehicles parking or turning into and out of accesses. If there is an on-street bike lane and the track is not offset there are concerns with bicycle-track interaction and bicycle wheels being caught in the embedded groove track.

Considerations for pedestrians:

Although the streetcar is not physically segregated in this scenario, pedestrians will be encouraged through engineering controls to cross at intersections or where controlled crossings exist. Pedestrian permeability on certain sections or streets (such as pedestrianised areas) can be accommodated if the City desires and depending on the context, particularly as the City has recently updated a bylaw that allows pedestrians to cross midblock on local streets. Controls could include reduced streetcar and motorized vehicle speeds, tactile and pavement markings to delineate spaces, signage, and education and awareness campaigns for all road users.

Stop locations must be strategic to minimize conflicts between road users and passengers boarding and alighting at stops. Stops can be informal at the curbside (which can result in inaccessibility if level boarding is not accommodated), or can be facilitated by a sidewalk bulb-out.

Considerations for cyclists:

Track type is a key consideration in designing trackways that cyclists may use, and is discussed in Section 4.3.

In general, cyclists should be enabled to cross tracks at an angle at or close to 90 degrees. As the angle decreases, the risk of catching a tire in the track increases.

Placement of on-street cycling infrastructure and the level of segregation it receives must be carefully considered to avoid conflicts. Cycling facilities, if not segregated, should be located in a way that minimizes the need for cyclists to enter the trackway to avoid other conflicts; cyclists should have an alternative exit route to the trackway.

As shown in Figure 3-10, Toronto's Roncesvalles streetcar cross-section includes the bike lane placed between the streetcar and the sidewalk. This may result in conflicts between boarding and alighting streetcar passengers and cyclists at streetcar stops if delineation and priority is not clear, but can also provide insultation for pedestrians from motorized modes.

Figure 3-10 Toronto Streetcar on Roncesvalles Avenue

NACTO's Transit Street Design Guide provides guidance on minimizing conflicts between cyclists, streetcars, and other road users, depending on the location of the tracks within the street. It suggests that curbside rail lanes be designed to be suitable for bicycling but require more width and typically require designs that let bicycles pass to the right of the streetcar at stops. However, as local access by bicycle is a component of nearly all urban streets, where possible, bicycle traffic should be positioned on a different section of the street, and parallel, high-comfort routes should also be provided.

Considerations for buses:

As with any mode sharing the streetcar right-of-way, buses can cause delay to streetcar operation. Bus stops could be placed in pullouts to avoid obstructing the streetcar, and should be sited in locations complementary to the streetcar route to enable multimodal linked trips.

Considerations for taxis and commercial vehicles:

As with any mode sharing the streetcar right-of-way, taxis and goods movement vehicles can cause delay to streetcar operation. These vehicles should be permitted to stop in pullouts to avoid obstructing the streetcar.

Considerations for emergency vehicles:

Trackways can be designed to accommodate use by emergency vehicles as trackway would be embedded and considered similar to other vehicle lanes.

Considerations for general purpose traffic:

As with any mode sharing the streetcar right-of-way, cars can cause delay to streetcar operation. In general, shared use streets should be lower-order streets not required to accommodate large volumes or high speeds for general purpose traffic, and where delays are unlikely to be frequent or sustained.

If parking is permitted, adequate width is required to ensure the minimum clear space between the streetcar and people entering and exiting vehicles, as shown in Figure 3-11.

NACTO's Transit Street Design Guide provides suggests that to keep transit lanes unobstructed, parking lanes adjacent to an offset lane should be up to 3.05 m wide when truck loading zones are designated or curbside deliveries are frequent.

Figure 3-11 In-Street (Offset) Shared Running with Parking – Portland

At stop locations, there are often issues with the platform encroachment into traffic lanes as motorists realize too late that the platform encroaches into their path. This can be mitigated by use of several strategies including providing signage, pavement markings and rumble strips as cues to indicate a shift to the other side of the lane is necessary.

For in-street shared running, the transverse position of the streetcar track within a lane needs to be critically considered. As noted in TCRP 155 Section 12.2.2, it is best to offset the centrelines of the track and traffic lane in order for rubber-tired vehicles to travel with their tires on paving which has a higher coefficient of friction. If there is an adjacent parking lane, poorly parked larger vehicles could foul the streetcar line and cause significant delays to the streetcar and vehicle traffic.

3.2.1.2 In-Street Segregated Running

The highest level of priority that would yield the highest level of operational efficiency for streetcar requires two tracks along the length of the corridor with as much segregation from adjacent users as possible. Combined with intersection signal priority, this would provide the fastest and most reliable streetcar operation and journey times and could be the basis against which other concepts are measured.

It is possible to construct the streetcar tracks within the road right-of-way and for it to be segregated from other road traffic. This is a common approach for light rail systems and is being proposed in Metro Vancouver for the South of Fraser Rapid Transit project. It is important to consider whole-system legibility, meaning that safety will be improved if all road users in the region have a common understanding of how streetcar operates and how to interact with it, whether in Surrey or Vancouver.

Laying out tracks in this way will allow the streetcar to generally follow similar signal phasing with other road users, but with segregated approaches, it will not be affected by queuing traffic.

Figure 3-12 In-street Segregated Trackway, Seattle

Centre Running

Centre running operation is often used to minimize impact to accesses and excessive influence along one side of the corridor. Widening may be required, or current uses may need to be reallocated, to accommodate stops, and is often required at intersections as turning movements across the tracks need to be controlled and may require dedicated lanes.

Side Running (Two tracks together on one side of road)

Side running alignments can be used where there are few or no access requirements on one side of the street. As with centre running, it is often necessary to widen the road at intersections as turning movements across the tracks must be controlled. This is necessary in order to minimize conflicts between the streetcar and vehicle turning movements, as approaching segregated streetcars are within a vehicle's blind spot and are often not seen. A primary consideration is for the addition of dedicated right turn lanes where typical driving policies permit right turns on a red light, as this would not be permitted with side running streetcar. The layout and control treatments need to be considered carefully to ensure that they are legible to all road users.

It should be noted that there is a precedent example of this configuration on the streetcar line from Granville Island to Olympic Village Station. During the Olympic demonstration, at Moberly Road, a combined through- and right-turn lane was permitted with turning traffic protected by active signs. While this may have been acceptable for the demonstration project and heritage operations which were relatively infrequent and operated at slow speeds, it is not considered good practice due to safety concerns as well as potential for traffic delay so may not be a feasible approach for a fully operational service.

Split Curb Running

Split curb running alignments site a streetcar track adjacent to each curb on a street. This configuration is not ideal for segregated in-street trackways but can be used where there is minimal to no access requirements on both sides of the street.

Considerations for pedestrians:

Streetcar stop locations, and access to stops, should be determined using the 7 Principles of Universal Accessibility as a guide. Stop access should be predictable, consistent, legible, and easy.

It is important in side- or split-running operations to ensure that streetcar stops are clearly marked to avoid forcing passengers to detour if they choose a stop serving the wrong direction.

Considerations for cyclists:

The most significant consideration for cyclists in this operating scheme is realized at intersections, when it is critical that the position and movement of the cyclist and the streetcar is predictable and obvious to both, and to other road users. This is achieved through signalization, pavement markings, and intersection design. NACTO provides guidance that can be applied for various types of intersections, relating to signalization, volumes, speeds, and geometry. In general, streetcars and cyclists should have protected or separate non-parallel movements at intersections.

Considerations for buses:

Bus stops should be sited in locations complementary to the streetcar route to enable multimodal linked trips.

Considerations for emergency vehicles:

Trackways can be designed to accommodate use by emergency vehicles, depending on track type and level of segregation. In most cases, it is recommended to use a mountable curb and/or drop bollards to enable emergency vehicle access within the trackway. Engagement with the emergency services would be required to agree appropriate procedures for such operations.

Considerations for taxis and commercial vehicles and for general purpose traffic:

In a segregated arrangement, the only conflict points between streetcars and these road users are at intersections. Conflicts are minimized through signalization, pavement markings, and intersection design.

3.2.1.3 Grade Separated Trackway

Where significant multimodal interactions are desired to be avoided, it is sometimes considered necessary to grade separate by building elevated guideways or underpasses, although this is more common for light rail systems than for streetcar. Grade separation would be required for crossings of active freight rail lines.

Overall, grade separated trackway will result in significant additional cost to the project, although speeds and reliability of streetcar operations are greatly increased. This may come at a trade-off to city-shaping and aesthetic goals the City aims to achieve, as visual and experiential impacts to other users at the street level will be different than with an at-grade system.

Figure 3-13 Edmonton Valley Line – Elevated trackway rendering

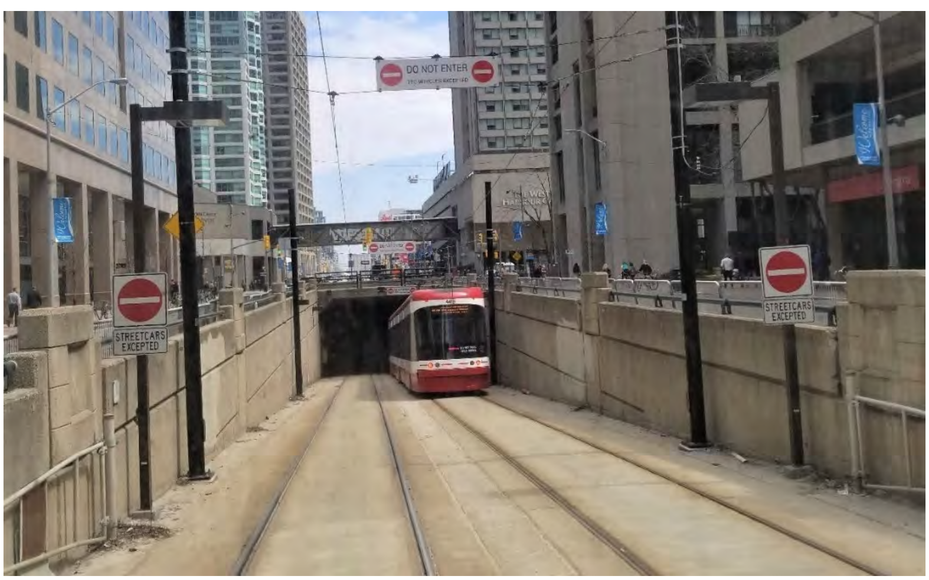

Figure 3-14 Underpass Grade Separation, Toronto, Canada

Grade separation is considered unlikely on the Vancouver streetcar as it is unlikely to fit with vision for the urban realm.

3.2.1.4 Couplet

A streetcar couplet consists of two single tracks located on parallel streets which operate as a one-way pair. The tracks can be sited within the road right-of-way either as an in-street shared running trackway or in-street segregated trackway, as previously discussed. A streetcar advantage of couplets is that they maximize the utilization of road rights-of-way, with flows in the same direction as street traffic.

Considerations for pedestrians:

Stops are required to be placed one to two blocks apart on parallel streets, creating wayfinding issues and potentially diminishing universal accessibility. They also decrease the legibility and intuitiveness of the system.

Considerations for cyclists:

Couplets make it easier to accommodate cycle tracks on the opposite the curb lane, thereby reducing conflicts between modes.

3.2.1.5 Single-tracking

Single track sections are possible where there are particular space constraints within a right-of-way, or where the mode hierarchy in a given section does not feature streetcar at the top. Single-tracking does come at the expense of operational flexibility, as conflicting movements will sometimes require streetcars in one direction to wait for trains in the other.

At-terminus

At terminus locations, it is sometimes easier to accommodate single track sections, although the length of single track should be considered carefully as there is potential to limit operational headways if one streetcar needs to wait for another to exit. The Canada Line provides a local example of this principle where the two southern termini have significant lengths of single track. As they currently operate trains at 6-minute intervals due to the truck line splitting into two spur lines, this long length is feasible. At the Waterfront station terminus, although there are two tracks, normally only one is used with the other used for a standby train. With the switches placed close to the terminus, it is possible to operate the 3-minute headway seen here.

There are many examples of single track termini including at the Wolverhampton Terminal of the Midland Metro in the UK. When originally constructed, two tracks were included. Over time, as one was rarely used, the maintenance of the required switch work became a liability and changes were made to remove one track.

Midway through system

There are many differing approaches to single track operation which are used world wide. In Nottingham, UK, a section to the north of the city uses single track sections of ballast track while alongside a passenger rail line. Passing loops are provided at stops and combined with switches and a full signaling system, and are used to coordinate operations. The switches also provide additional flexibility as trams can use them to turn back.

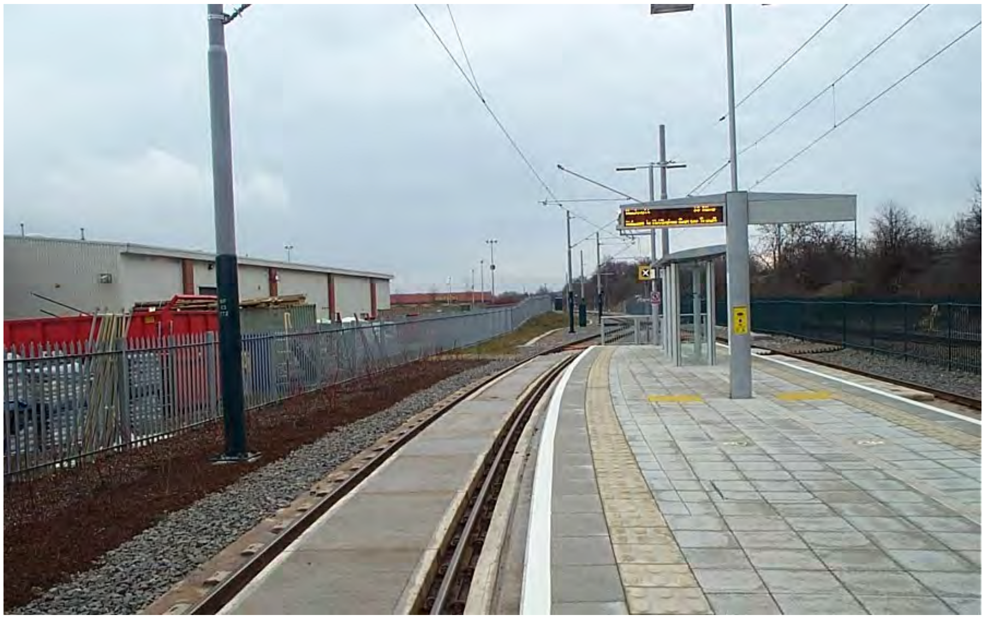

Figure 3-15 Nottingham Stop on single track section

A different approach is seen in Amsterdam, where along the narrow Leidsestraat, interlaced tracks are used, widening to two tracks over bridges. This involves laying four rails in the street and does not require switches. Where the sections of interlaced track are short, it is possible to operate without complex signalling, utilizing priority rules and line-of-sight. However, with modern systems and in a North American context, this may not be desirable or acceptable.

Figure 3-16 Interlaced track in Leidsestraat in Amsterdam

(credit: Wikipedia)

The restrictiveness of a single-track section will depend on the frequency of the service, as well as the location and length of the single-track section. If it is possible to construct a timetable where services are unlikely to meet at the location in question then it may not be too disruptive to regular service.

Disruptions

As noted in the sections above, single track sections with switches can provide opportunities to turn back services. However, this could come with constraints on the ability to operate frequent headways or on disrupted timetables in order to recover services. With a streetcar service, particularly if there are fully shared sections or intersections where it is difficult to achieve high levels of priority, it may be a common occurrence for streetcars to meet at the location of a single-track section.

3.2.2 Priority through Signals

One of the key factors in determining the travel time of a streetcar is its performance through intersections. Unlike other random events that can affect travel times, delays at intersections can be largely mitigated in design, primarily through traffic control systems and strategies.

Individual streetcars can request priority at upcoming intersections by communicating with signal controllers; priority can then be provided through a number of traffic control systems. These can range from straightforward strategies that simply provide green lights to the streetcars to more complex strategies that look to provide a balance between the streetcar operation and that of the remaining traffic.

Traffic control systems are more effective when the streetcar has a level of track segregation. Where other traffic can impede the progression of the streetcar along its tracks, predicting when the streetcar will arrive at the intersection is a lot less accurate. The travel time between a priority request and when the streetcar arrives at the intersection becomes a lot more random due to the presence of other vehicles blocking, queueing or turning.

As a general rule of thumb, priority for one traffic movement at an intersection will come at the expense of the other traffic movements and/or pedestrian movements. This is particularly evident when this priority is provided by changes to an intersection’s regular operating pattern in order to facilitate a discrete event.

The range of priority that is afforded to a streetcar can range from full priority (signal preemption) where the streetcar would be guaranteed greens at all intersections down to zero priority where the streetcar would be subject to a typical multimodal signal operation. Most solutions would attempt to provide a balance between the two.

Level of streetcar priority can be informed by:

- mode hierarchy and desired level of service for each mode
- desired streetcar journey times and envisaged public perception (both of which can impact ridership numbers)

The following methods are all possible options to provide differing levels of signal priority to the streetcar. Which should be implemented may well vary by location and will need to be confirmed closer to the time of implementation.

3.2.2.1 Signalling Coordination (Passive Priority)

The most efficient signalling strategy to ensure quick passage of streetcars through intersections would be for the streetcar to always arrive at an intersection during the traffic phase favouring the streetcar’s progression. As a starting point, signal coordination along the streetcar corridor to favour the streetcar would reduce the likelihood of delays at intersections with minimal effects on cross corridor traffic or turning movements.

This can be achieved by basing the offsets between the phase timing of successive intersections on the average travel time it takes for streetcars to get from the one intersection to the next. This can create “a green wave” for streetcars so that users experience a continuous movement between streetcar stops.

However, streetcar-based signal coordination would provide no relief if the streetcar were to arrive at an intersection during a red light. The streetcar would then need to wait for the signal phases to tick through until it receives a green.

To provide priority to the streetcar when this occurs, advanced signal timing solutions are required.

Considerations for pedestrians, cyclists and vehicles:

Often by providing coordinated signals to the streetcar this will also have benefits for the other modes that are travelling parallel to the streetcar. They will also benefit from not having to stop at intersections. However, this can impede the movement of other modes crossing the streetcar alignment as their signals may not be coordinated.

3.2.2.2 Pre-emption

Pre-emption is a traffic engineering strategy that ensures that a streetcar will receive the highest level of priority at an intersection. A request for priority is sent from the streetcar to the signal controller. The signal controller will then attempt to complete whatever traffic phase is happening to run a green phase for the streetcar. When the request is received early enough, this results in a direct green for the streetcar, otherwise the next phase enabled will be the streetcar green.

The pre-emption protocol does not take into account the pre-programmed signal cycles and will always respond positively to the priority request. This gives the largest benefit to the streetcar’s continuous operation without having to be delayed at intersections.

Considerations for pedestrians, cyclists and vehicles:

The downside of this approach is the disruption to the overall traffic operations. Every pre-empted phase interrupts the normal signal cycles to allow for the streetcar to proceed. The seemingly ad-hoc signal plan prevents proper signal coordination with other signals along the corridor.

The unexpected changes to the traffic signal pattern caused by the pre-emption call can lead to confusion and frustration for road users who anticipate phases as per the usual signal cycle. Furthermore, the additional phase changes will increase the amount of overall yellow and all-red time where traffic is not as efficiently passing through the intersection.

Considerations for emergency vehicles, garbage and recycling trucks, city maintenance vehicles:

Pre-emption systems can also be used to engage automatic retractable bollards which have been proposed at a few accesses and laneways for the Arbutus Greenway to keep traffic out whilst allowing for emergency, transit, garbage vehicles, etc. The retractable bollards could be accessed (lowered) by these select vehicles but only when it is deemed safe as streetcar is not approaching or have triggered pre-emption.

3.2.2.3 Transit Signal Priority

Transit signal priority (TSP) is a traffic engineering strategy that provides a higher percentage of green time to the streetcar when needed, but it is not always provided a green indication immediately on arrival at the signal. A request for priority is sent from the streetcar to the signal controller. The signal controller then determines if the request should be accommodated based on pre-determined parameters (i.e. whether the transit vehicle is behind schedule or priority was provided on the last cycle for the same approach). The application of the TSP can be further defined so that it is implemented only when certain conditions are met, e.g. with regards to preceding phases being catered for and pedestrian calls, and omitted when not deemed necessary. This potential added flexibility can enable greater responsiveness by the signalling plan with regards to traffic levels and demand, but could reduce the reliability of the streetcar with regards to adhering to the timetable.

The TSP system consists of traffic signal controllers that are programmed to provide a green aspect for approaching streetcars. There are various techniques that can be applied such as green extension, early green, phase insertion, phase omission and phase rotation.

A green extension extends the green light for compatible vehicle phases upon detection of an approaching streetcar. In coordinated signal phasing, the extension does not change the signal timing phase but merely holds the streetcar light green and only works if the light is already green as the streetcar approaches. If uncoordinated, the signal can be extended for an extended period of time until the vehicle checks in on the other side of the intersection or the maximum extension is exceeded. In that case, there can be an effect on the timing phase.

Another technique is the application of early green, which only works if the light is red as the streetcar approaches. The traffic controller will shorten the green light seen by the opposing traffic, thereby truncating the red signal for an early green display.

The phase insertion technique allows a streetcar phase to be inserted within the normal signal sequence when a streetcar is detected. Typically, this is a leading left turn, however, some traffic signal controllers allow the streetcar phase to be inserted in many different locations within the signal cycle, depending on the time of detection. This function should be carefully evaluated before applying because of the many possible insertion points.

Considerations for general purpose traffic and other modes:

Phase insertion often does not meet driver expectancy because of its disruptive nature. Since phase insertion is a user defined parameter, it should be mutually agreed upon by both the streetcar operator and traffic operations.

Phase rotation shuffles the order of the phases at the intersection so that the needed phase is provided upon arrival of the streetcar. For example, a signal controller with phase rotation enabled could switch from a normal leading left to a lagging left sequence if a left-turning streetcar is expected to arrive after the normally scheduled leading left phase would end.

3.2.2.4 Adaptive Traffic Control Systems (ATCS)

Adaptive Traffic Signal Controls are a more advanced strategy system which has the potential to provide greater priority to streetcar and less disruption to other traffic flows. The system relies on a greater level of detection and communication between streetcars and the traffic control systems.

Whereas the engineering strategies mentioned above deal with a single vehicle communicating with the next upstream signal controller, adaptive signal control is a concept where all the relevant traffic and signal controllers in a network communicate with each other to make signal adjustments far in advance of any streetcars arriving at intersections.

Adaptive signal control uses algorithms to autonomously adjust signal parameters in real time to respond to actual traffic conditions, in this case specifically the locations of the streetcar vehicles within the network. This spontaneous optimization can result in decreased travel times, reduced delays and shorter queues.

The systems are dependent on good detection capabilities and may not necessarily communicate with existing signal control systems in place, meaning that a significant investment may be required.

The different ATCSs employ specific and complex methods and algorithms to achieve the intended signal control. These are often difficult to replicate within simulation models and will require input from the ATCS providers and additional coding to properly model.

Examples of adaptive control systems include the Split Cycle Offset Optimisation Technique (SCOOT) as used heavily in light rail systems in the UK and Dallas; the Sydney Co-ordinated Adaptive Traffic System (SCATS) and Real Time Hierarchical Optimized Distributed Effective System (RHODES), which are further expanded upon below.

SCOOT - Split Cycle Offset Optimisation Technique

This is a standalone complete and fully adaptive system with full management system capabilities initially developed in the UK in the1970s. The system gathers data from detectors and processes information to optimize traffic splits, cycle lengths and offsets between lights based on signal timing theory; however, it requires a larger area of operation in order to gather sufficient data to analyse. Key attributes include fast responses to changes in congestion and easy tie-in with specific vehicle (streetcar/transit) detectors or automatic vehicle location systems. It has been used in a variety of instances within the City of Toronto, although not along streetcar corridors.

SCATS - Sydney Co-ordinated Adaptive Traffic System

This is a standalone intelligent computerized traffic management system that makes incremental adjustments to traffic splits, cycle lengths and offsets dependent on detected traffic flows. It uses a library of traffic plans within a central computer to identify the best solution depending on traffic conditions. It has been piloted in the City of Toronto through implementation at 12 intersections along Sheppard Avenue East between Neilson Road and Meadowvale Road.

RHODES - Real Time Hierarchical Optimized Distributed Effective System

RHODES uses peer-to-peer communications to distribute information about traffic volumes across multiple intersections on a corridor. The system predicts the amount of volume arriving at an intersection 60 seconds out and can either extend or terminate greens based on the upstream numbers detected. The system is simplistic and is geared to improving flow along a single corridor only, but it can be geared to give greater priority to streetcar vehicles using the technology and philosophy.

InSync

InSync uses cameras mounted at an intersection to determine vehicle numbers and delay for said intersection and then applies the best phase to serve the traffic at the time and communicates the decision with other intersections. Global Optimization, an InSync add-on, can create progression over a corridor by creating “green tunnels” so that traffic can progress without needing to slow down. This can be applied specifically to streetcars or transit vehicles. The downside of this system is that the optimization is corridor specific and can negatively affect off-corridor traffic.

OPAC - Optimization Policies for Adaptive Control

The OPAC adaptive control system uses a predictive optimization with a rolling horizon. Splits, offsets and cycle lengths (though not phase order) are adjusted to maximize throughput at lights based on data arriving from detectors 15 seconds upstream; however communication between network intersections is limited.

3.2.2.5 Vehicle Detection

For any active TSP system to work, some form of vehicle detection is required. This can either be hardwired, by means of detection loops or transponders, or virtually, by means of on-board GPS/RF/optical activation.

Detection points are normally required at a set distance from the traffic intersection, to allow enough time for the TSP strategy deployed at that intersection to initiate the TSP sequence. Secondary detection points are also typically deployed closer to the intersection to confirm arrival of the streetcar at the intersection, and at the opposite side of the intersection, to signal clearance of the streetcar off the intersection.

In the case of pre-emption systems, the offset distance of the first detection point must allow sufficient time to clear all conflicting movements for the worst-case scenario, which is normally determined by the conflicting pedestrian phase. For example, if the streetcar arrives at the detection point at the moment a green walk aspect was provided for the pedestrian phase, the minimum time to clear the intersection must be respected. The detection point must be placed sufficiently far in advance of the intersection to allow this time to lapse while the streetcar advances at maximum posted speed.

An example of a scheme where hardwired detection is used is shown in Figure 3-17. Loops along the track receive a signal from an on-board control unit through a wayside Train to Wayside (TWC) device. In this illustration the detection point in advance of the intersection decodes such a message and passes it on to a non-vital logic controller (NVLC). The term “non-vital” is used to distinguish from much more expensive “vital” systems that are required when the safe passage of trains depends on the integrity of the system. For a detection scheme such as this, safe train operations are maintained by the traffic controller (TC) at the intersection, allowing a much more cost effective non-vital system to be used for annunciating positioning.

From the detection point, the local non-vital logic controller relays the message to a receiving non-vital logic controller which is co-located with the traffic controller at the intersection. This is normally achieved via communication cabling along the trackway; however this could also be achieved by data radio links between the non-vital logic controllers. Through physical handshaking with the traffic controller, the detection condition is registered with the traffic controller to initiate a TSP phase.

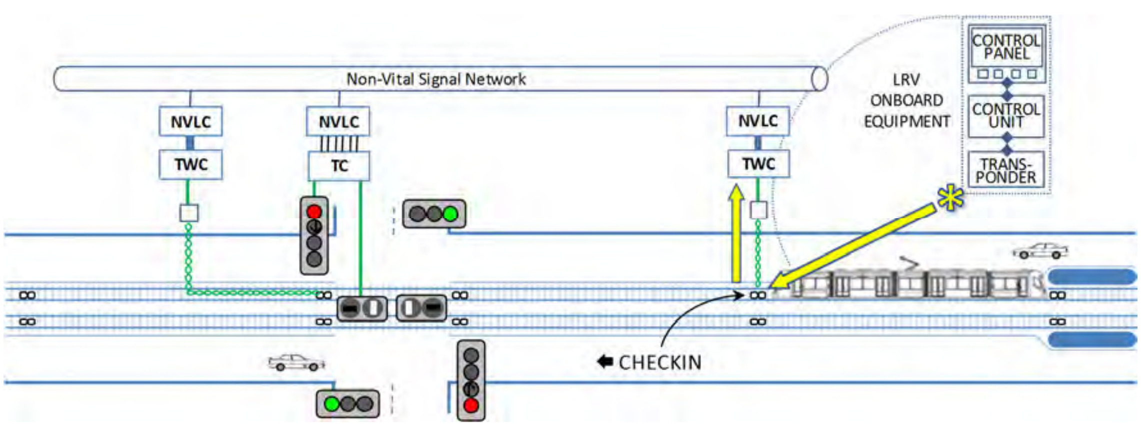

Figure 3-17: TSP Hardwired Vehicle Detection Scheme

A major disadvantage of hardwired detection points is the lack of flexibility they provide for changing conditions with the infrastructure. An example for the case of conflicting pedestrian movements could be the impact of designing countdown timers to accommodate slower pedestrians. Such a change after the detectors are installed would necessitate that they physically be moved to provide the longer detection distance needed for the longer clearance time.

Virtual detection works by means of on-board equipment that is aware of the streetcar's true position at all times (usually by means of GPS positioning, or by combination of track transponders and odometer readings) and relaying detection point positioning by data radio to the traffic controller location. This provides many advantages including reduced infrastructure requirements and greater flexibility in defining detector locations (by programming). Adoption of virtual detection is still in its infancy which presents higher technology risk in the short term; however, in the long term this will very likely render hardwired detector systems obsolete. Some early adopters, such as Baltimore light rail system, are reporting success with vehicle mounted train equipment communicating using spread spectrum radios to traffic controller locations. Implementation of TSP systems using virtual detection systems provided by Opticom has provided benefits for various bus operators, leading to increased ridership Laval, QC and travel time reduction for buses in Memphis, TN. Furthermore, this technology has already been adopted to varying degrees by transit buses and emergency responders, and it would be beneficial to maintain compatibility with these.

3.2.3 Priority through Traffic Management

The introduction of the streetcar will result in shifts in the traffic patterns along the transit corridor. This will occur naturally due to the disruption caused by the streetcar operation either through new flow limitations along the route or delays at intersections for conflicting traffic movements.

The natural changes to traffic flows also presents an opportunity to influence changes to traffic patterns in the network and mode shifts. This can be done by reprogramming signals as discussed in Section 3.2.2. It can also be done by reconfiguring routes either to be particularly beneficial in developing a new route into a city area or to be detrimental to an existing traffic route that the City of Vancouver may wish to discourage.

3.2.3.1 Re-routing of Traffic

There are other, non-signalling solutions that can be used to implement changes to the current traffic patterns. Modifying road access can be challenging and dangerous as road users who are familiar with a route may not be vigilant to signage changes and other protections. The introduction of major infrastructure changes, especially those associated with a significant construction period, is a good opportunity to introduce these types of changes, as people will often adjust their travel patterns to avoid construction elements or may have had to react to road closures during construction.

Eliminating Turns

Eliminating turning movements that conflict with the streetcar movements is an effective way of improving individual intersection performance for both the streetcar and general traffic. It is also an efficient way of channeling traffic either away from or onto the corridor.

Eliminating a turning movement at one intersection will not only directly affect that intersection but will also have a knock-on effect on multiple adjacent intersections which will serve as the alternative routing. These intersections will have to deal with additional traffic to offset the advantage gained at the eliminated turn. The net effects can only be determined once the specific modifications have been identified. However, one of the key advantages of a grid system is to provide flexibility and choice to the road user, and eliminating routing options is often met with opposition by public who are used to a certain degree of freedom while driving.

However, the elimination of turning movements can result in a more effective and optimal signal plan/ cycle splits. This can increase the likelihood of a streetcar seeing green, provide greater flexibility to the signalling and decrease queueing at the modified intersection.

Considerations for general purpose traffic and commercial vehicles:

By eliminating turns, access and circulation through a neighbourhood can be dramatically impacted. Careful consideration for how residents access their neighbourhoods should be given.

Considerations for commercial vehicles:

For commercial vehicles there are designated routes through the city so it is critical not to eliminate a turn from one route onto another. Also, often buildings and commercial destinations have specific loading bay configurations and access. It is imperative to work with businesses to understand their commercial vehicle needs and access requirements.

Introduction of One-way Streets

Modifying a street from two to one-way is a significant endeavour to undertake and has a significant impact on the local traffic network. However, it is an effective approach to manipulate traffic flows.

A one-way street can benefit from superior traffic flow, better safety and an improved streetscape environment. It would also result in more space available for the streetcar operation which can be used for greater segregation, more space for platforms, and the ability to reduce conflicts in traffic movements.

However, the endeavour is a significant change. Street signage and geometry will require modification, and ensuring that there is no loss to accessibility and mobility is a key study which would need to be undertaken. Mitigating for any losses would be a prerequisite to changing any existing street's access and/or direction.

Reversible Lanes and Bi-directional Lanes

Where space is limited for lanes, and traffic flows swing based on peak hour movement, a reversible lane may be an option that could be considered for corridor traffic. Reversible lanes are most commonly associated with the approaches to major pieces of infrastructure which can serve as bottlenecks such as bridges and tunnels.

Reversible lanes differ from bi-directional lanes in that they only serve one flow at a time. Bi-directional lanes are uncommon in urban environment; when encountered they are often in the form of turning lanes where neither direction has the right of way and vehicles are only expected to engage the lane for left turns. Bi-directional lanes help traffic flow in that they remove delays caused by mid-block left-turning movements, but otherwise they do not offer much benefit to road capacity and would not be particularly advantageous for the streetcar operation.

A reversible centre lane offers more advantages, although would require infrastructure (lights, signs, road markings) to ensure a safe operation. There are examples of urban roads heavily used by commuters which operate reversible lanes at peak hours, although not necessarily coordinated with a streetcar operation. Similar to the section of West Georgia Street approaching Stanley Park, Avenue du Parc in Montreal is an example of a corridor that operates a reversible centre lane coupled with side lanes in both directions reserved for public transport during rush hour. Connecticut Avenue in Washington DC is another example of a road with reversible lanes used to good effect in a very urban environment.

3.2.3.2 Public Transit Road Options

The City of Vancouver's strategy with regards to how streetcar will sit among the hierarchy of public transport services within the target area will help define whether changes should be made to the existing transit network to support the streetcar's growth and ridership.

Changes to existing bus routes, whether small local changes that affect the routing in a finite area or wholesale overhauls to existing routes are more palatable when major infrastructure changes are introduced.

The most common changes seen are:

- Truncation of existing routes that the future streetcar is effectively replacing along important sections of the route;
- Implementation of new localized services to partly service the new streetcar using vehicles that have been freed up by streetcar implementation; and
- Changes to routing of existing services in key areas of the streetcar route to improve traffic movement or facilitate interchange.

Transit Mall

Transit malls are sections of streets where transit vehicles are given either exclusive or prioritized access over private automobiles. The removal of the congestion caused by private vehicles eliminates a key cause of delay. Transit malls can often easily be converted into more pedestrian-friendly areas and can benefit from lower vehicle operating speeds while maintaining transit capacity. The benefits of transit malls are more apparent on systems where the streetcar runs on in-street shared tracks, as segregated streetcars are less affected by traffic. Another key benefit to transit malls are a greater ease of interchange between streetcars and other forms of public transit. This can be partially replicated to a lesser degree by simply having multimodal stops.

Figure 3-18 Östra Hamgatan, Gothenburg, Sweden - Transit Mall

King Street corridor in Toronto is an example of how removing traffic from a corridor can improve streetcar performance with an increase in on-time arrivals leading to a 16% increase in ridership since the implementation of a pilot project to limit the number of cars on the corridor over 13 blocks by removing left turns and on-street parking as well as limiting through movement.

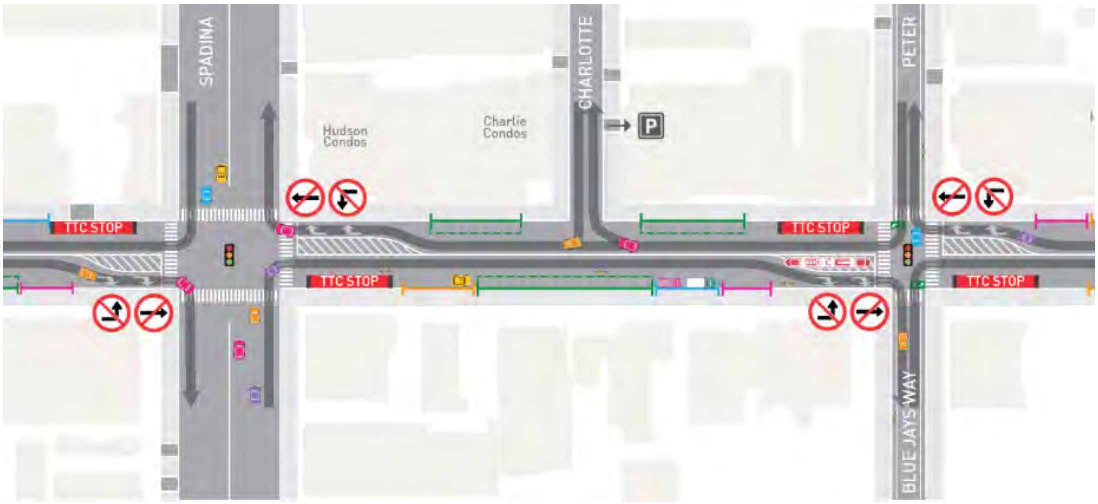

Figure 3-19 King Street Toronto – Traffic removal pilot program diagram
(credit: City of Toronto)

The potential downside to transit malls is that general traffic has one less corridor to use. Where there are sufficient alternative routes, this is not a problem, but where there are only a few routing options, traffic can be impacted from pushing traffic away from a certain route. Furthermore, local businesses are often opposed to any move that is perceived as limiting their visibility to potential customers and moves parking away.

Counter-flow Lanes

A counter-flow or contraflow lane is a lane in which traffic flows in the opposite direction of the surrounding lanes, most often used for public transit or bicycle lanes on primarily one-way streets. These offer a level of flexibility to the public transit operation that regular traffic may not be able to benefit from.

Figure 3-20 Counter-flow lane for Tram Operation in Hong Kong
(credit: Google Maps)

3.2.4 Safety Treatments

Determining the appropriate safety treatments to apply at intersections can be challenging where local standards do not already exist. In the case of Edmonton's Valley Line LRT project, research and evaluation of treatments from other comparable systems across North America was performed, and a technical basis for design recommendations was developed for all crossings of at-grade intersections in the corridor.

The Valley Line low-floor urban system will operate using line-of-sight principles, controlled by the traffic signal system on the city streets. The operating speeds allow for operation of trains in the street system without gates and high levels of segregation.

An Intersection Hazard Analysis and Treatment Report was developed, specific for the project, to provide detailed guidelines in selecting safety and operational treatments for crossing intersections on the alignment. References used in developing the guidelines included the Manual on Uniform Traffic Control Devices (MUTCD), Transit Cooperative Research Program (TCRP) Report 137, and best practices from other agencies.

The goal was to present a methodology for evaluating intersection hazards and selecting appropriate treatments to mitigate safety concerns, while applying the least intrusive treatments first until the hazards were mitigated. The order of preference for least intrusive to most intrusive was:

- passive signs, markings, and tactile paving;
- striped channelization;
- traffic signals, active signs and pedestrian crossing signals;
- removal of sightline obstructions such as trees;
- reduction of vehicle speeds;
- vehicle on-board audible devices;
- barrier channelization;
- other pedestrian protection devices such as swing gates; and
- automatic grade crossing warning systems (which were ultimately not applied at any intersection).

If adopted in Vancouver, the choice of which treatments to employ would be assessed on a case-by-case basis depending on the requirements and environment of the intersection being evaluated.

4 Ancillary Streetcar Considerations

4.1 Transit Performance and Operations

Transit performance will be a key consideration when determining transit priority and implementing streetcar. *TCRP 88: A Guidebook for Developing a Transit Performance-Measurement System* provides guidance for establishing a performance-measurement system that addresses customer-oriented and community issues.

With the performance in mind, the operational parameters can be developed. Some typical operational parameters that are used to estimate typical run-times include:

- Dwell time of 20 seconds at stops;
- Several slower speed areas where pedestrian interaction is anticipated to be higher;
- Normal average operating speed of 40 km/h where conditions will allow; and
- Partial priority at major intersections leads to the need to stop and incur a delay of at least 10 seconds, and up to 45 seconds (depending on the intersection complexity, cycle time, TSP approach used).

Some systems will specify performance based (reliability) guidelines. One example is Zurich Public Transport (VBZ), which outlines the following performance measures:

- No more than a 10 second delay at signalized intersections (where signalized intersections are necessary)
- Travel time variability no more than +/- 5% over the whole route

It should be noted that in previous downtown streetcar studies and a subsequent report to council discussed the use of 8-minute headways.

4.2 Stops

Streetcar stops are how passengers interact with, board and alight, the streetcar vehicles. They are a key part of how the streetcar integrates into communities and with other modes.

4.2.1 Stop Features

Streetcar stops are best likened to bus stops with improved amenities. Stops can be scaled to integrate with their operating context, often blending in with a sidewalk or plaza.

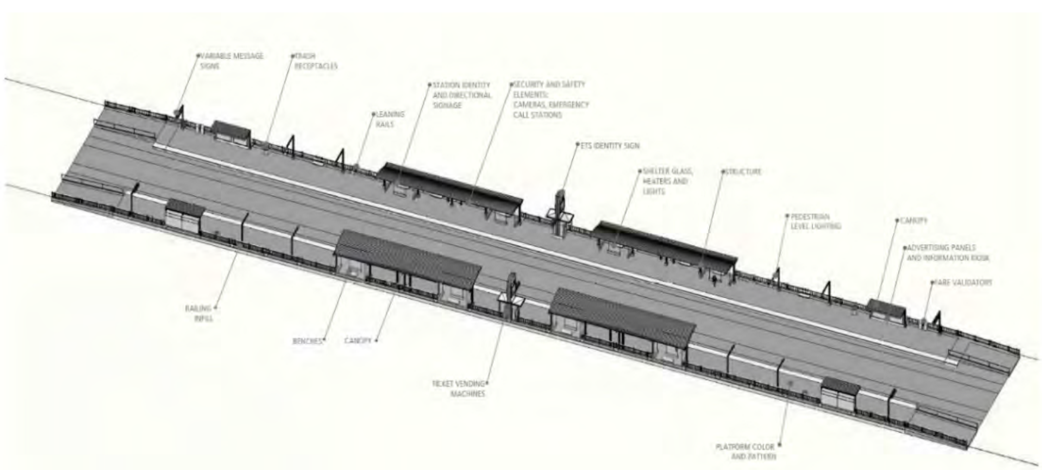

Figure 4-1 Typical Stop Components, Edmonton Valley Line

(credit: City of Edmonton)

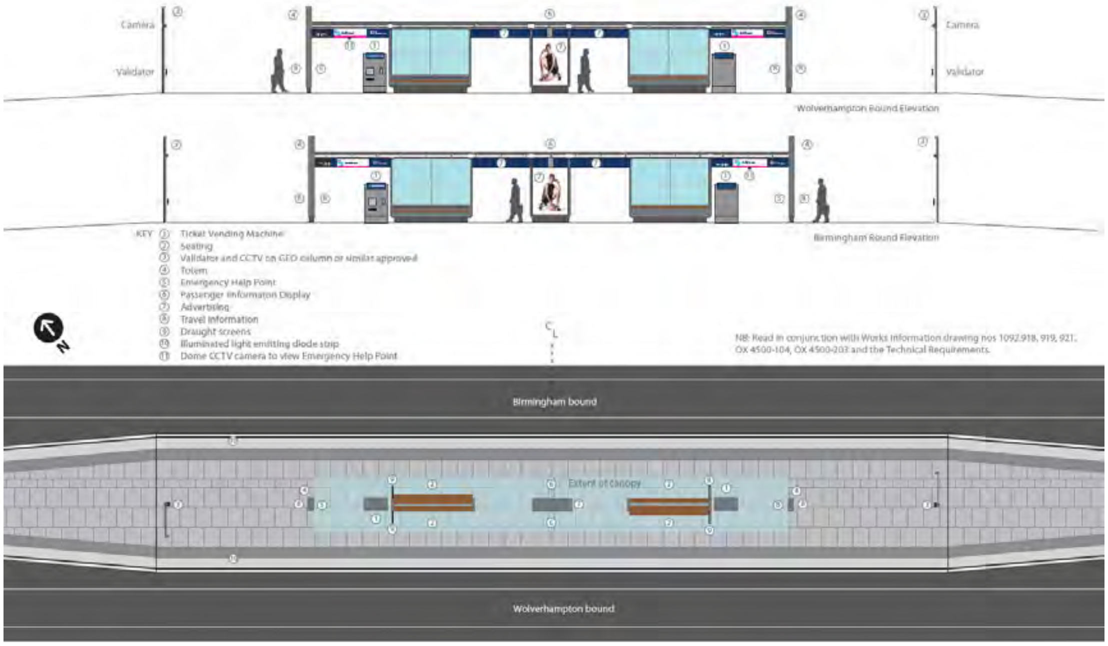

Figure 4-2 Typical Stop Component – Birmingham, UK

While contemporary streetcar stops are deliberately understated and minimalist in order to blend into their surroundings, "statement" stops that vary in size and aesthetic can be curated / procured if desired.

The Vancouver streetcar will be integrated with the urban and natural contexts of the city, and stop platform heights will be approximately twice the height of a standard curb. This will allow step-free boarding so that the system is universally accessible.

Figure 4-3 Accessible Stop Platform in Barcelona

4.2.2 Stop Configurations

There are three typical stop configurations that may be applicable for the Vancouver Streetcar network:

4.2.2.1 Centre-Loading

At a centre-loading stop, tracks pass on each side of the platform and passengers board and alight to the middle of the tracks before crossing one to reach their destinations. Some transit authorities prefer this configuration, particularly where the trackway is in the middle of a road as it keeps waiting passengers further away from traffic. Additionally, it can have wayfinding benefits as passengers choose the correct streetcar direction one on the platform. This configuration is typically used at terminus stops to provide operational flexibility, or at major activity centres with high passenger volumes.

Centre platforms can be slightly more efficient, since infrastructure such as ticket machines and shelters can be shared. However, they generally require the tracks to separate apart, adding curves into the alignments.

Figure 4-4 shows two examples of centre platforms from Birmingham, UK and Zaragoza, Spain as well as an approach to a centre platform where the tracks separate and the potential treatments which can be applied to these areas.

Figure 4-4 Centre Platforms

4.2.2.2 Side-Loading, Standard Layout

At a side-loading platform, streetcar passengers board to a platform at one side of the tracks in a similar way to how buses unload passengers at the curb of a road.

Figure 4-5 below shows two different side loading platforms from Nottingham, UK. The first photo shows a more suburban location where the vehicle is in its own right-of-way and the platforms link into a park area. The second photo shows the city centre where the vehicle is shared with road traffic and the platform is integrated with the sidewalk behind.

Figure 4-5 Side Platforms in Nottingham, UK

4.2.2.3 Side-Loading, Staggered Layout

Similar to the side-loading standard layout, passengers board to a platform at one side of the tracks in a similar way to how buses unload passengers at the curb of a road. This configuration has two platforms separated slightly, for instance one can be placed south of an intersection and the other to the north, depending on available space.

This configuration is often utilized on centre-running alignments where property is limited, as the platforms can be in the 'shadow' of the left turn bay on the opposite side of the intersection. One adverse affect of this layout is that the overall stop limits extend further along the trackway longitudinally. Consequently, vertical grade is another important consideration as the trackway is constrained over a greater length.

Recommendation: The feasibility study concepts to show variations on these stop types to best suit the neighbourhood and community context, as well as the road configuration. Based on the typical stop features and free space required for loading Table 4-1 outlines the design parameters:

Table 4-1 Streetcar Stop Design Parameters

Parameter	Proposed Criteria	Comments
Platform Length	35 m	Consistent with NEFC assumptions and allows for a wide range of vehicles which are nominally categorized as 30 m but can be slightly longer. Would also allow 40 m LRVs to be used as long as the doors are set greater than 2.5 m from each end and other infrastructure is sufficiently distant from the end of the platform.
Clear space on loading edge of platform	Minimum 1.5 m	Sufficient to allow for a wheelchair passenger movement.
Platform Width – Side	3 m preferred 2.5 m absolute	Consistent with NEFC. 2.5 m is the absolute minimum required to accommodate items such as ticket machines and shelters, and allow circulation on the loading edge. Could potentially be combined with adjacent sidewalk as long as sufficient clear space (1.5 m) is maintained along the loading edge and platform sized to accommodate ridership and pedestrian flows.
Platform Width - Centre	6 m preferred 4 m absolute	4 m is the minimum required in order to accommodate items such as ticket machines and shelters and allow circulation on each side.
Platform Height	300-350 mm	Typical height above top of rail for modern streetcars
Horizontal platform gap	50 mm	ADA requirements
Track centre to platform edge	1375 mm	
Length of tangent beyond platform ends	10 m	
Platform Gradient	2%	Derived from ADA regulations and consistent with TransLink requirements for platforms on rail based systems
Ramp length	6.0 m preferred (1 in 20) 3.6 m minimum (1 in 15)	

4.2.3 Multimodal Platforms

4.2.3.1 Shared with Buses

It is possible for streetcar stops to be shared with buses in order to provide more seamless and integrated connection between the streetcar and bus services. This is done in the Downtown Seattle Transit Tunnel where King County Metro buses and Sound Transit Link light rail both stop at shared bus-rail stations. However, the frequency and timetable of the streetcar and buses needs to be carefully coordinated as to not delay each other from making a stop or adding a delay to the journey time.

It is often not advised for both modes to share a stop since when buses share the same section as the streetcar, there may be issues with the durability of the surface of the embedded section at the stop. The embedded section is subject to horizontal breaking forces. Also, there is an issue with joints along the rails.

Additionally, as streetcar vehicles and buses have different static envelopes and clearance above the road and/or track level, it is often not advised for both modes to share platforms in the long term. The nose of a bus (i.e. front bumper) is lower than typical streetcar platform heights and thus will clip the platform edge as they pull into the stop. This will damage both the bus and the platform edge, and is a durability and maintenance concern.

4.2.3.2 Shared with Road Traffic

There are some examples of streetcar stops that locate the passenger waiting area at the pedestrian walkway or sidewalk with the roadway between the edge of the pedestrian walkway and the track being raised to form the platform. Once the streetcar approaches the stop, the road users are required to stop prior to the raised section of road, using signals and barriers, in order to allow for passengers to board or alight.

Examples include the Royale-Châtelet stop in Orleans, France, as well as multiple locations in Vienna and Melbourne.

Figure 4-6 Royale-Châtelet stop in Orleans, France
(credit: Wofgang Wellige via http://www.railfocus.eu/public-transport/orleans/index.html#6)

This is unlikely to be a recommended solution for the Vancouver streetcar as it would be unusual to introduce such an aspect on a new system.

4.2.4 Stop Location and Spacing

Typically, streetcar stop spacing is similar to bus stop spacing, allowing passengers to board and alight at stops that are typically placed between 300 – 800 m apart. The more frequent the stops are, the longer the streetcar's runtime, due to the cumulative deceleration, dwell, and acceleration time at each stop as noted in Section Transit Performance and Operations. Therefore, stop spacing is a factor in operating speed and therefore overall system performance.

Most systems will have varied stop spacing depending on the context of system and neighbourhoods they are travelling through. An example is Calgary, AB where stops along its existing high floor LRT lines are typically spaced over 1 km apart in the suburban areas, and then spaced every 2-3 blocks (approximately 500m) along the 7 Avenue transit mall in the downtown area.

4.3 Track

There are generally four types of streetcar track finishes – embedded, ballast, direct-fixation, and green-track. Track types can change along an alignment and can be tailored to the environment and desired aesthetic.

Design considerations that should be taken into account for later stages of the project include but are not necessarily limited to:

1. Aesthetics – should the rails be visible, obvious, or concealed and what surface finishes are required to blend the tracks with the aesthetic of the neighbourhood.
2. Segregation
    a. Will people, vehicles, cyclists, and other road / greenway users be permitted to cross the tracks or enter the trackway?
    b. Will the tracks be physically inaccessible at certain locations (i.e. switches), or for the length of the trackway, and by whom?
    c. Do emergency vehicles need to be physically able to cross or enter the trackway?
    d. Is it important to provide a clear delineation for where people are and are not permitted to be?
3. Maintenance – Ease of access and maintenance
4. Cost – capital and operating

The different options will be considered in the context of specific locations during the feasibility study stage of this project.

4.3.1 Embedded Track

With embedded track, the streetcar rails and track bed are embedded in concrete, asphalt, pavers, or other material used in roadways. The top of the rail is flush with the top of the surface it is embedded in. It is typical for urban systems where the streetcar crosses or is integrated with traffic and/or plazas.

The finished surface can vary significantly depending on the use or the context it is situated in. If integrated with the road then it will need to be suitable for road traffic whereas tracks through a plaza space could have a surface that is complementary to the surroundings. Finishes can range from simple concrete or asphalt, through coloured or textured concrete to setts or pavers. All uses will need to allow for adequate drainage of the surface although that can involve shedding water onto adjacent landscaped areas if possible in order to provide a more sustainable solution. The trackway should be designed appropriately to work with other elements, and accommodate accessibility and safety with other road users.

This type of finish can provide an aesthetically pleasing solution which can integrate with surrounding surface finishes. However, using the same surface finish as the adjacent surface can defeat the advantage of changing the surface type, which can often act as an indicator to show where people are and are not permitted to be.

Thus, as a minimum it is recommended that the streetcar dynamic envelope is indicated (e.g. painted line or line of different pavers).

Once constructed, embedded track requires minimal maintenance until the rail becomes overly worn and needs to be replaced. Doing so can be time consuming and expensive as it is necessary to break out and then restore the surrounding surface finishes. On areas of light wear, rail replacement may only be required after 20 years or longer. On heavy wear areas, such as tight curves, embedded rail replacement can be required more frequently although proper design and regular upkeep will maximise the rails' life. This requires a sufficient budget for repairs and replacement.

Figure 4-7 Embedded Track from Dublin Luas

Figure 4-8 Embedded Track from Midland Metro at Bull Street Stop and Corporation Street

4.3.2 Ballast Track

With a ballast solution, the track bed consists of ties (concrete or timber) sitting on top of ballast (gravel), which is in turn supported by a compacted foundation. Ballast track is often used for heavy rail and was the type of track which previously was in place for the majority of the Arbutus Corridor and corridor between Granville Island to Cambie Street. Typically, it is used in more segregated areas with minimal interaction or intersection with other modes of transportation. It provides clear indication to the areas occupied by the streetcar. Ballasted track is perceived to be less integrated in an urban environment than embedded and green track options.

Ballast track is economical to construct but often requires that more space is allocated to the streetcar, as construction and maintenance tolerances mean a wide envelope must be prescribed. It requires more frequent maintenance than other types of track form as it can move and shift over time, and is repaired by a process called tamping. Some maintenance activities such as tamping can be noisy so may not be desirable in some of the residential areas of the streetcar corridor(s).

While ballast track will allow rainwater to permeate through the top layers which surround the ties, it must be laid on a compacted foundation which will not permit infiltration. These foundation layers will require sub-drains which may be able to permit infiltration if the ground conditions permit.

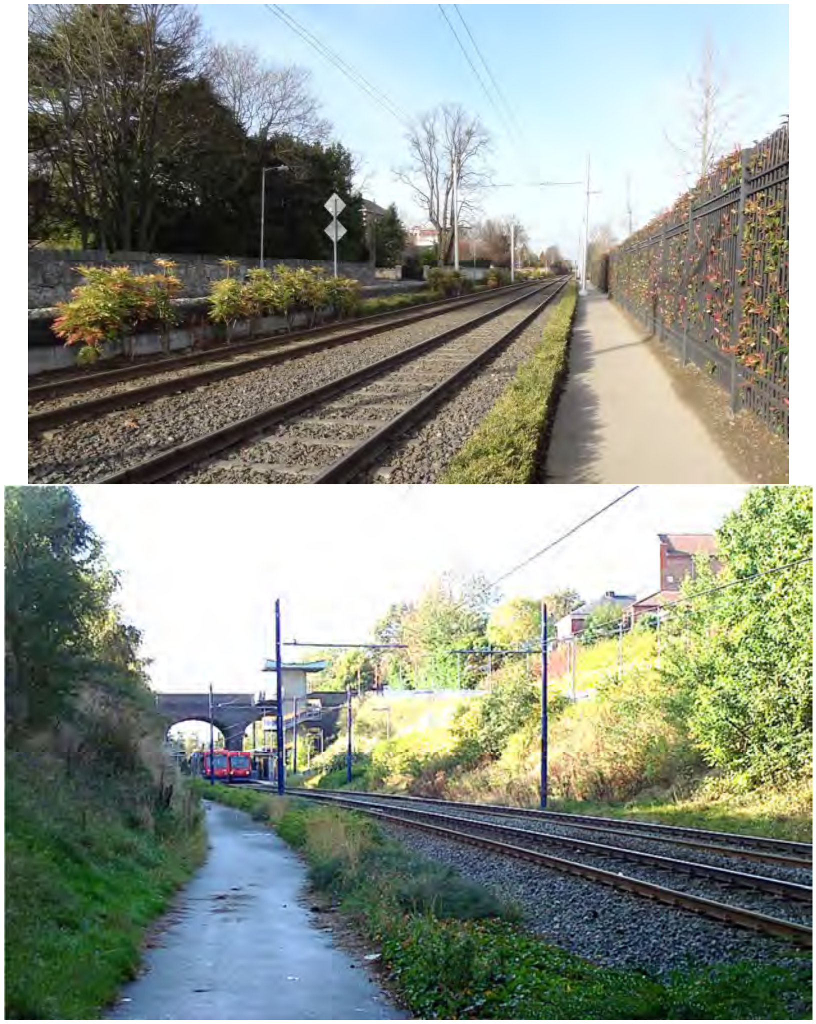

Figure 4-9 Ballast Track from Dublin Green Line and Midland Metro, Birmingham, UK

4.3.3 Direct Fixation Track

Direct fixation (DF) track consists of rail and fasteners mounted on concrete plinths or track slabs, as shown in Figure 4-10. The top of the rail is typically 350-400 mm above the top of concrete slab. It is most typically used on structures (such as bridges or tunnels) in areas where the streetcar is not required to share the trackway with pedestrian or vehicular traffic. Similar to ballasted track, DF track is perceived to be less integrated in an urban environment than embedded and green track options.

This type of track form is probably the most desirable from an operations and maintenance perspective. The concrete rail support means that like embedded track, the rail is held securely in place. However, as the rail is not encased in concrete, it is easy to inspect and replace when it is necessary.

With the rails standing proud of the surrounding surface, DF track provides clear indications that the area is reserved for the rail system and could be used where there is clear separation between streetcar and the other adjacent modes.

As with embedded track, it may be possible to shed water from the support slabs to adjacent landscaping.

Figure 4-10 Direct Fixation Track from Dublin Luas

4.3.4 Green Track

Green (or grass) track is really a subset of the other types of track as each of the embedded, ballast and DF track solutions can be modified to incorporate a green finish. While ballast track can be overlaid with grass or other plants, doing so limits the ability to maintain the ballast, so it is not frequently used.

More commonly, a similar track bed to embedded or direct fixation is used with vegetation (grass, sedum, wildflowers) in between and adjacent to the rails. There are many different types of construction which can be considered; some provide a full concrete slab below the trackway, while others utilize a series of beams and plinths to support the rails, allowing at least some areas around the tracks which may permit infiltration of rainwater. It should be noted that grass track is not always green (drought conditions, drainage issues or winter), and is not suited to every operating environment.

Green track also has the benefit of providing softscaping within the trackway which has noise and microclimate benefits. It is accepted that green track provides a noise reduction compared to typical ballast and embedded track. The quantity of the reduction is dependent on the location of the vegetation in relation to the top of rail, as well as characteristics of the vegetation including coverage rate, density, height and water content. The typical reduction of noise levels compared to ballasted track is approximately 2 dB(A) and 5dB(A) compared to embedded track with a hard surface. The reduction in noise and vibration effects are particularity important at sensitive receptors which may include hospitals, schools, sound recording studios, and residences.

Grass track provides microclimate benefits through reducing the urban heat island effect by reducing hardscaped areas that absorb and retain heat, and by evapotranspiration. Evapotranspiration cools the air by using heat from the air to evaporate water.

With the implementation of green track, it is necessary to pay particular attention to details in the design and the appropriateness of green track to the jurisdiction and environment. Careful consideration of maintenance, stray current, and selection of plant species is necessary for a successful system.

Figure 4-11 Green Track from Berlin, Birmingham, Freiburg, and Munich

4.3.4.1 Influence on Pedestrian Behaviour

Since urbanely integrated streetcar systems are still relatively new to North America, there are concerns that green track could be mistaken for parkland with pedestrians not paying attention to approaching trains. This is not a problem in Europe where such systems are much more commonplace. Thus, clear delineation between green track and adjacent landscaping or public realm spaces is recommended.

4.3.4.2 Implementation with Green Infrastructure

Any drainage features need to be located away from the track in order to not compromise the track structure itself. However green track itself contributes significantly to sustainable drainage practice (compared to slab track or embedded track) as it slows down the run-off and stores the water in the soil.

4.3.5 Special Trackwork

Special trackwork consist of switches and crossings to allow streetcars to diverge onto different tracks or for individual tracks to cross each other. They can be complex to construct and if placed within shared sections of track can be vulnerable to damage.

Crossovers are typically required at terminus locations to allow streetcars to change direction and as well as at locations where multiple lines meet. When possible, they are also placed at regular intervals throughout a system to allow emergency turnback when disruptions occur.

Special trackwork can be designed to accommodate all types of track finish.

4.3.6 Track Construction

There are three main options for construction of trackforms other than ballasted track (embedded track, slab on-grade) as outlined below:

- Cast-in-place

  The rails are installed either bottom-up (direct fixation on previously cast concrete slab) or top-down (temporarily suspended using jigs).
- Cast-in-place with prefabricated components

  Track Structure Systems comprising of precast components embedded in in-situ concrete are considered monolithic systems. The prefabricated components are manufactured to high precision which are embedded in concrete poured in-situ, thus allowing greater tolerance on the in-situ concrete work compare to purely cast-in-place systems.
- Precast units

  Track Structure System comprising of precast slab units. Typically channels are provided in the slabs in which the rails will be installed. The precast units are generally about 6 m in length, are manufactured to high precision and are fully detail designed well in advance of installation on site.

From previous project experience, an in-situ system with pre-fabricated elements which is a hybrid between typical direct fixation (cast-in-place) and precast systems are very favorable in reducing construction time.

The construction staging of tracks is highly dependent on the level of segregation of the tracks, space constraints, and construction performance requirements. Some systems will construct both tracks at the same time, often when segregated or centre-running. Others may construct one track at a time in order to reduce the amount of road space/lanes that are closed at a given point in time.

This can be looked at further and considered as feasibility concepts are developed but will ultimately be up to the contractor.

4.3.7 Gauge

The standard gauge in North America is 1435 mm, measured at 15.9 mm below the top of rail in accordance with TCRP Report 155.

4.3.8 Rail Profile

The following rail profiles are typically used:

- For embedded track (straight) and open track forms, 115 lb rail
- For embedded track (curves with radius < 150 m), grooved rail 60R2 (EN 14811)
- For embedded track (special trackwork according to VDV), grooved rail 60R1 (EN 14811)

4.4 Environmental

4.4.1 Noise and Vibration

Noise and vibration are key considerations for a streetcar systems, and ones that are often of high public interest.

To be most cost-effective one needs to consider noise and vibration throughout a project, as late consideration may preclude some treatments due to procurement and implementation time.

It is often best to consider the track and vehicle as a system with interaction of the wheel and the rail being responsible for the bulk of wayside noise and vibration impacts.

4.4.1.1 Noise

There are a couple sources of noise on streetcar systems that need to be carefully considered as a streetcar system is designed and implemented.

Wheel-Rail Interaction

These are sources of wheel-rail noise mechanisms:

- Rolling noise
  - Typically, the dominant source from streetcars which can be controlled through proactive maintenance
- Impact noise
  - Caused by loss of contact between wheel and rail often from irregularities or as vehicles travel through special trackwork
- Curving noise (squeal)
  - Produced by streetcars travelling through tight curves as a wheel set is unable to align its rolling direction tangentially to the rail thus resulting in wheel flange contact with the rail head
  - Can be mitigated through use of lubrication (grease or water) with consideration for loss adhesion

Interior

There are several sources of noise on-board a vehicle including the noise from traction motors and their associated cooling fans and vehicle auxiliary equipment (e.g. HVAC, brakes, horns). Interior noise of streetcar vehicles can be mitigated through use of noise-absorbing floors (e.g. wood floor, floating floor with noise-absorbing mats), ceiling lining and seat covers, as well as tightly closing doors and windows.

4.4.1.2 Vibration

Modern LRT and streetcar systems will often require that the LRVs must be compliant with ISO and EN standards to achieve suitable ride comfort for passengers.

4.4.2 Climate (Weather)

It is good practice on streetcar systems to carefully consider the weather and climate. Each system and city with have different considerations as they have different environmental and climate situations.

Ice and snow will be an issue in the winter. With embedded track, ice can build up in the groove and be a concern for derailment. Thus, good de-icing practices should be implemented and regular ice and snow clearing to occur. Also with snow, snow clearing of the tracks and coordination with snow clearing of the roadway will need to be considered.

It is also good practice to keep streetcar rails clear of organic debris (i.e. leaves), particular in the autumn. The Canada Line has experienced traction issues and wheel slippage when wet oily leaves fall onto the rails. Thus, regular cleaning and maintenance of the tracks is required.

4.5 Operations and Maintenance Facility

Streetcar vehicles will require a facility in which to be stored and maintained. Space requirements for such a facility are determined by fleet size and the required maintenance intervals. General considerations for facility planning include the size and type of vehicle, the requirements for staff facilities and whether an operations control centre is required.

Considerations include the following:

- Operational flexibility for start and end of service
- Minimizing reversing movements/change in direction, as it requires driver to change ends which adds time
- Number of maintenance bays (heavy, light)
- Maintenance equipment (e.g. wheel truing machine)
- Vehicle washings
- Staff parking
- Material storage/laydown area

4.5.1 Location and Integration with Urban Environment

There are examples of operations and maintenance facilities being sited within urban areas. In Portland, the vehicle storage and maintenance facility, which is located under the Interstate 405 viaducts structure, houses 10 streetcars as well as the staff.

Figure 4-12 Portland Streetcar Maintenance Facility
(credit: Google Maps)

In Seattle, the First Hill Streetcar Operations and Maintenance Facility is located in an area that is primarily industrial and commercial. The building's front façade is modern and blends into the urban environment, while the back has a single track leading into the yard and facility which is a spur line leading from the mainline tracks a couple blocks away.

The location and requirements of a maintenance facility for Vancouver's streetcar will be addressed further in the feasibility study.

4.6 Traction Power

Traction power is the electrical energy (usually in the form of direct current (DC)) that propels the streetcars. A traction power substation (TPSS) is the electrical installation, usually located on land owned and operated by the system operator, that converts the primary (alternating current (AC)) electric power from the electrical utility service to the appropriate voltage, current type and frequency used by the streetcars. The overhead contact system (OCS) is the distribution system, consisting of feeder wires, contact wire, messenger wires, and return track circuits, which feeds energy from the TPSS to the streetcar.

4.6.1 TPSS

4.6.1.1 TPSS Spacing

There are two approaches for the spacing of TPSS locations. With higher power capacity systems, similar in nature to light rail systems, TPSS facilities can be quite large (1 Mega Watt (MW) – 5 MW) requiring approximately 120 m^2 of land, which can be very impactful in terms of both land costs and streetscape integration. Thus, a primary project design objective for light rail type systems is to size them larger and space them as far apart as can be practicably achieved, typically 1 to 2 km.

Streetcar systems can have much lower power capacity requirements (depending on loaded vehicle weights and frequency of service) that can work with much smaller TPSS facilities (~ 500 kW or less) spaced closer together, typically at 800 m spacing. These can be architecturally enhanced and placed on smaller sites (approximately 50 m^2) thereby having less impact on land costs and streetscape integration, as shown in Figure 4-14.

Figure 4-13 Architecturally Enhanced TPSS Housing – Winston-Salem

In addition to these smaller land acquisition requirements, other advantages of smaller, more frequent spacing of smaller TPSS locations are:

- The utility service may not require an expensive primary utility feed if it can be fed from the local residential distribution system;
- Lower need for underground or overhead parallel feeder wires;
- Lower return rail voltages;
- Less stray current; and
- Greater flexibility in the siting of TPSS locations.

Other design trade-offs to consider when determining spacing are operational reliability, utility availability, distribution infrastructure (size and number of OCS wires and feeders), and operating voltage.

Operational Reliability

From an operational need, TPSS spacings are almost universally determined by n-1 criteria, whereby a defined service (usually full peak service) can be maintained while any one TPSS is out of service. TPSS sizing and spacing to support this requirement can be confirmed during preliminary design by means of computerized load flow analysis.

Greater spacing can be achieved by accepting a degraded mode service during single TPSS outages. However, with one TPSS out of service, this can result in higher maximum track voltages and greater voltage drop on the overhead system.

Utility Availability

Substation spacing also needs to consider availability of the utility distribution system providing energy to the substations. Adjacent TPSS locations may not provide full redundancy from utility disruption in cases where they are both fed from the same utility substation. Depending on location, the added cost of supplying energy from more distant utility substations needs to be weighed against the likelihood of a utility failure.

If redundant utility services are readily available, a system could be provided with dual utility feeds and supply equipment in each TPSS which provides a highly reliable system. Where this is done, greater spacing can be achieved between TPSS locations without sacrificing reliability (although the impacts of higher messenger and parallel feeder requirements need to be factored).

Distribution Infrastructure

A method to increase TPSS spacing is by adding parallel feeder cables to reduce overhead resistance and voltage drop. This can be done by adding parallel messenger wires on the OCS, which has been done in Edmonton, or by adding parallel underground conductors, which has been done on the Luas and Bergen systems.

Adding parallel messenger wires will result in unsightly overhead clutter as well as drive the requirement for more robust and visually intrusive OCS poles. There is also a case of diminishing returns in adding additional parallel underground conductors, as the additional copper and associated duct bank costs can become prohibitive.

Operating Voltage

The further an LRV is operating away from a TPSS, the larger the voltage drop between the TPSS and the streetcar. This is caused by line losses in the wiring as current flows through it. If the voltage drop is large enough, the streetcar may no longer be able to operate.

Voltage drop can be minimized in a number of ways. One way is through additional infrastructure as previously described. Another is by operating at a higher voltage. Although 750 VDC is the typical nominal operating voltage in North America, some systems, such as Ottawa LRT and Seattle LRT, have implemented 1500 VDC systems. The higher voltage allows each LRV to draw approximately half the current resulting in lower line losses, thereby allowing greater TPSS separation. However, this results in higher track voltages (which have safety implications) and induces more stray current (which can corrode underground metallic objects such as re-enforcing bars and pipelines). Also, since 1500 VDC is not yet predominantly used, not all vehicle manufacturers are prepared to supply vehicles at this rating.

Voltage support between TPSS locations can also be achieved by introducing energy capture systems such as flywheel technology (as is currently under evaluation by LA Metro) and intermediate super capacitor installations. Although these can allow further TPSS spacing, they do have some land impacts to house the equipment.

A comparison of TPSS design selections used by other streetcar and light rail agencies is provided in Table 4-2. A cost/benefit analysis should be undertaken to confirm the appropriate spacing/sizing options given Vancouver's high real estate values and land availability.

Table 4-2 TPPS Design Criteria – Other Agencies

Agency/System Name	System Classification	TPSS Highlights
Portland Streetcar	Streetcar	• Single Wire OCS • 800 m TPSS spacing • 500 kW TPSS • 3 m x 6 m TPSS footprint • Residential utility supply
Seattle Streetcar	Streetcar	• Joint use trolley bus/streetcar substations • Similar design to Portland Streetcar
Winston-Salem	Streetcar	• Single Wire OCS • 500 kW TPSS • 4 m x 6.5 m TPSS footprint • Residential utility supply
Washington DOT	Streetcar	• Single Wire OCS • Parallel Feeders • 1.2 km TPSS spacing • Residential utility supply
Kansas City	Streetcar	• Single Wire OCS • Parallel Feeders • 800 m TPSS spacing
Edmonton Valley Line	LRT	• Contact Wire and Multi Messenger OCS • 1.0-1.5 km TPSS spacing • 1.0 MW TPSS • 7.5 m x 19 m TPSS footprint • Primary utility supply
Phoenix (Valley Metro)	LRT	• Contact Wire and Messenger OCS • Parallel Feeders • 1.6-2.4 km TPSS spacing • 2.0-2.5 MW TPSS • Primary utility supply

4.6.1.2 TPSS Sizing

TPSS facilities can either be free standing buildings which are built in place, or can be prefabricated and shipped to site as illustrated in Figure 4-14. The advantage of pre-fabricated structures are lower costs and typically smaller footprints.

Depending on loading and spacing requirements, TPSS equipment ratings can vary from .5 MVA up to 5 MVA. Pre-fabricated structures are typically not feasible for larger (>2 MVA) facilities.

Figure 4-14 Pre-fabricated TPSS Housing – Edmonton Valley Line

4.6.1.3 Locations

Each TPSS should be located in reasonably close proximity to the tracks with an outer limit of 100 m. They need to be accessible at all times but can be located inside buildings or compounds to disguise them. For instance, several facilities such as the TPSS, signal housing and communications room can be co-located within a single utility complex surrounded by architecturally attractive fencing.

Having a single freestanding substation design across the project is the simplest from an electrical design point of view, but may not be visually optimal.

If necessary, and if there is a tolerance for significant ventilation, they can be placed in chambers underground. The first stage of the Luas system successfully used some underground substations, although this causes some additional design issues of access and ventilation.

4.6.2 Overhead Contact System (OCS)

Historically, streetcars have used pantographs or trolley poles to collect electric power from overhead lines. Overhead lines are familiar in Vancouver from the network of trolley buses which operate across the city. Streetcar OCS can be designed to be relatively unobtrusive, generally with only a single wire supported above each track. The poles required to support the OCS are often decorative and can become a signature element of a system. In many European applications, wires are supported by building fixings but it is unclear whether the legislative powers to require this would exist for the project. However, it may be possible to reach agreement, particularly with new developments, to facilitate these fixings and therefore reduce ground level infrastructure.

Figure 4-15 Decorative poles with cantilever supports in Birmingham

Figure 4-16 Single Wire OCS in Barcelona

Figure 4-17 Dublin Luas with Single Wire OCS

4.6.2.1 OCS Intersections

As Vancouver has an existing trolley bus system, it is important to consider the effect of streetcar and trolley bus OCS line intersections in the design of the overall system, as the trolley bus OCS at intersection locations is typically complex requiring the need for major redesigns (if possible) to accept any streetcar OCS. The left image of Figure 4-18 below shows an example of a relatively simple (i.e. one of each line crossing) intersection in Seattle, WA. This arrangement requires the street car pantograph to “jump” the gaps created for the (higher) trolley bus lines to run through. Other than the obvious additional construction cost, this adds complexity to operations as streetcar drivers will be advised to “coast” through the intersection to minimize the risk of electrical arcing. It also adds potential failure points to the system and therefore additional maintenance costs to manage reliability. Best practice is to eliminate these intersections, or to minimise them where unavoidable. When complex intersections are involved (i.e. busy roads where multiple streetcar or trolley bus routes pass through the same intersection), the impacts quickly escalate and should be avoided where possible.

A potential solution for Vancouver, given the existing trolley bus network, may be to procure vehicles with an on-board energy storage capability, similar to what has been done in Seattle, WA for the First Hill Streetcar line which includes the streetcars being supplied with on-board traction batteries to allow them to operate off-wire for distances up to around 1.6 km, with their pantographs lowered. This allows streetcars the ability to operate for reasonable distances without the need for an OCS. The cost of this functionality on the vehicles can be traded off against the savings in the system as a whole. This should be considered on a case-by-case basis. The example shown in the right image of Figure 3-12 depicts an intersection of two bus lines and one streetcar line intersecting. In this image, a second streetcar line proved too complex or costly to integrate to the intersection. It was therefore necessary to implement vehicles with on-board energy storage in order to have the ability to apply tractive power along this road in that direction. Refer to Section 4.6.4 for further information on on-board energy storage.

Figure 4-18 Seattle Streetcar and Trolley Bus OCS Intersections

4.6.3 OCS Types

There are three basic types of OCS in general use for supplying overhead power to lower speed electric rail vehicles (three other types exist for high speed train operations). The design intent in all cases is to provide uninterrupted current collection, without sparking or loss of contact. This becomes more difficult to achieve as the vehicle speeds increase.

4.6.3.1 Simply Suspended OCS

The simplest form of OCS consists of a single contact wire or trolley wire, usually having fixed terminations at each end. At each support, the wire is suspended at a single point, so that no vertical movement of the wire relative to the support is possible, although the support itself may be either rigid (as a cantilever) or flexible (as a span-wire or headspan affixed to either poles or buildings). This is the most commonly used solution for streetcar systems where speeds are relatively slow and do not exceed 50 km/h.

Figure 4-19 Simply Suspended OCS - Span Wires Affixed to Buildings, Sheffield, UK

Figure 4-20 Simply Suspended OCS - Span Wires Affixed to Poles

Figure 4-21 Simply Suspended OCS - Affixed to Cantilever Poles

Due to the limited current carrying capacity of the single contact wire, this type of system is normally complemented by parallel feeder cables either mounted on the OCS supports or in underground ductbanks, which is preferred where urban integration is a priority. The parallel feeder is connected to the contact wire at 200-300 m intervals.

4.6.3.2 Bridle Suspended OCS

The flexibility and performance of the OCS can be improved by providing the contact wire with a flexible support in the form of a bridle. This is more commonly used in LRT systems where speeds can operate to 80 km/h. The contact wire may either have fixed terminations or be automatically tensioned. Parallel feeder requirements are similar to the simply suspended OCS.

Figure 4-22 Bridle Suspended OCS - Affixed to Cantilever Poles

4.6.3.3 Simple Catenary OCS

A simple catenary OCS system typically consists of multiple wires; a contact wire and a messenger wire. The contact wire is supported from the messenger wire by means of hangers, which are spaced such that the sag of the contact wire between them is comparatively small. The messenger wire is fixed to the supports without any vertical flexibility. This type of system may either have fixed terminations or be automatically tensioned. A second voltage support wire may also be provided alongside the messenger wire.

The maximum speeds attainable with simple catenary (level contact) are 90 km/h with fixed termination and 120 km/h with automatic tensioning.

Figure 4-23 Simple Catenary OCS (Single Messenger Wire)

4.6.4 On-board Energy Storage

In more recent times, alternate options for energy have become more common. Some systems are now moving, at least partially, to on-board energy storage systems, such as supercapacitors and batteries, to provide power in locations where overhead wires and the poles that support them are not desirable. These systems will have different requirements for TPSS facilities, potentially requiring smaller but more frequent provision, most commonly in close proximity to stops, where charging will take place.

Figure 4-24 Charging Point at a Stop – Seville, Spain

Currently, on-board storage system technology is advancing with more new and existing streetcar systems adopting this technology, including in North America. The demand for automotive hybrid technology and the associated research and development (R&D) work being carried out by the automotive industry is helping to reduce the overall costs for this technology including life cycle costs (LCC). On the back of this the rail industry, particularly in the light rail and streetcars areas, is benefiting from this by being able to offer promotors/owners the opportunity to incorporate this technology to mitigate for such things as conflicts with trolley bus OCS and for aesthetic reasons.

There are obvious pros and cons associated with this technology including the distances that can be traveled, particularly when in shared traffic where there is a risk of delay, and may limit operational flexibility. Vertical grades anticipated on the network are another important factor when considering these technologies. However, there are new systems that are using on-board technology even for steep gradients. For example the new city center extension to the Midland Metro streetcar system in England, includes retrofitting a fleet of CAF streetcars with batteries to allow them to operate OCS free on a 9% gradient (approximately 150 m long) and up to approximately 2.4 km with charging being carried out at the terminal stations.

A recent controlled out-of-passenger service test using one of the CAF streetcars fitted with batteries resulted in a distance of 28 km being achieved. However, in practice this level of OCS free operation would not be used in passenger service because the battery life would decrease significantly. Given the likely timelines before streetcar is implemented in Vancouver, the technology will have moved on further and may be a commonly-adopted solution at the time of Vancouver streetcar implementation.

4.6.5 Ground Level Power Systems

Ground level power systems propagate the energy from the TPSS through a ground-based infrastructure rather than the OCS. This can be done either with a contact or contactless system.

In a contact system, small sections of contact rail are energized only when a streetcar is present over each section, with the energy transferred through a pick-up shoe that rides along the surface of the contact rail. Protection against electrocution is provided by continuously de-energizing each section of rail where no streetcars are present. Figure 4-25 illustrates a contact system in Bordeaux, France where the power rail can be seen between the running rails. Note that the pantograph is lowered although conventional OCS can be seen for vehicles that are not equipped with pick-up shoes, although many sections of the system no longer have OCS. It is worthy of note that these ground-based systems that use a pick-up shoe device are not typically used in climates where snow and ice prevail due to potential contact issues.

In a contactless system, a magnetic field inductively transfers power from coils in the guideway to pick-up coils located underneath the streetcar.

Both types of systems are proprietary, and require that streetcars and guideway infrastructure be sole sourced as a system from a single supplier. They are also quite costly in comparison to conventional OCS because they require more infrastructure including the traction power supply switching system and cabling located at regular intervals beneath the roadway/track along the guideway. This significantly complicates track design and makes maintenance more challenging.

Figure 4-25 Bordeaux France Contact System

4.7 Systems

4.7.1 Automatic Block Signals

Since streetcars operate with other street traffic, they are subject to the same line-of-sight operational precautions that apply to all traffic. This negates the need for a block signalling system to maintain safe train separation in most instances; however there are certain circumstances where this could be warranted on a limited basis.

4.7.1.1 Reverse Running

Reverse running, also referred to as "single tracking", is a means of operating around a disabled section of track where separate tracks are normally available for each direction of travel. This is achieved by inclusion of crossover locations along the alignment to shunt streetcars from one track to the other. This is typically not possible where tracks are fully shared with road traffic.

Where the possibility of reverse running exists, extra precautions need to be considered when operating under line-of-sight. Since a streetcar could be travelling towards an opposing streetcar on the same track, the operators on both streetcars would need to be able to stop within half the range of vision (as opposed to just within the range of vision), which will impose additional restrictions on operating speeds. This can either be mitigated by implementing operational procedures to restrict speeds only when reverse running is known to be in effect, or by providing block signals to govern the entry into any section of track at each crossover location, so that multiple streetcars operating on the single-track section at any given time are always travelling in the same direction.

An example of how this protection is provided is with the Washington DC FDOT streetcar system, where a train-to-wayside communications system is provided that interfaces with both the wayside signal controllers and devices that activate the powered switch machines. The train-to-wayside controller has provisions for both the manual entry of routing codes and for entry of pre-determined routes. For executing routes, the system activates and sets the crossovers while providing an indication of streetcar location to the control centre. Automatic operation of powered crossovers are interlocked and governed by block signals to ensure two streetcars cannot occupy the same section of track that could result in unsafe situations.

Furthermore, devices known as mass detectors are used to prevent the actuation of any crossover when a streetcar is passing through or occupying the crossover.

4.7.1.2 Terminals

Terminals are the end of line sections where streetcars change direction and are shunted from one track to another. This can be provided by means of a rudimentary approach such as having the streetcar enter a preferred pocket track at the terminal platform through a self-restoring track switch. However, should a more robust approach be used to allow use and storage of streetcars on both terminal pocket tracks, power operated crossover switches with block signals protecting the switches could be considered, similar to the approach discussed for reverse running.

4.7.2 Central Control System

A centralized control system is normally desirable to allow incident management and network monitoring to be performed at a mission command centre. In the past, separate and dedicated systems were deployed to perform centralized tasks such as:

- Central dispatch system, to monitor streetcar location and perform crossover routing,
- Supervisory control and data acquisition (SCADA), to monitor and control traction power systems,
- Building management system, to monitor and control building infrastructure (fans, elevators, escalators),
- Network management system, to manage information technology systems (network switches, routers, power supplies),
- Public address system to relay information to passengers at stops, and
- Security system to manage access and perform intrusion detection.

There are now systems available that can provide supervisory functionality for all these subsystems in one package.

A human-machine interface (HMI) presents a common graphical interface to the central operator for each of the subsystems. This will support simplified and common access, reporting, recording/storage, and utilization of the infrastructure.

Additional functionalities are expected to become available as these systems continue to evolve.

4.7.3 Communications

Communications infrastructure will be required to provide connectivity between a main data centre, typically co-located with the control centre, and wayside devices at TPSS locations, stops, traffic intersections and perhaps crossover locations. This is normally provided by means of a fibre optic backbone, installed within a cable duct bank extending horizontally underground alongside the alignment.

Breakout of the fibre optic backbone is usually provided through buried cable access vaults located close to each wayside location where connectivity is required.

All wayside communication devices should support remote IP connectivity through local IP switches, and use Power over Ethernet (PoE) wherever practical to reduce AC power distribution requirements. Local UPS devices should be sized to provide adequate backup power capabilities to these devices (typically providing 4 to 8 hours of backup).

4.7.3.1 TPSS

Data connectivity from the data centre will be required to manage local SCADA RTUs (remote terminal units), which will provide remote monitoring information such as alarms, current draw, line voltage, and switching status. Remote control SCADA functions will also be necessary for switching control and transfer trip functionality.

Building management control will also be required to manage heating and ventilation and to monitor building alarms including smoke, heat and gas detection alarms.

Connectivity will also be necessary to support CCTV cameras and emergency telephone stations which may be placed within the TPSS compound.

Access to all TPSS communicating devices can be provided from IP PoE switches co-located with RTUs and other alarm panels within a small communications housing within the TPSS compound.

4.7.3.2 Stops

Communication at stops are required for passenger wifi, CCTV cameras, emergency telephones, fare collection, public address and variable messaging signs. Access to these devices can be provided from IP PoE switches housed within a platform-mounted cabinet.

The fare collection head end may not reside at the mission command centre since a different corporate entity may be responsible for this. If so, low speed data connectivity will be required between the data centre and the fare collection head end facility. This can be provided by leased data facilities if extension of the fibre optic backbone is not feasible.

4.7.3.3 Traffic Intersections

Since traffic controllers are integral to TSP operation, remote data connectivity to the traffic management centre is highly desirable, as are video feeds from intersection CCTV cameras. Since the traffic management centre is unlikely to be co-located with the streetcar mission command centre, it may be necessary to provide high speed data connectivity between the data centre and traffic management centre. This can either be provided by means of leased facilities, or extending fibre optic cabling between existing city traffic data network facilities and the main data centre.

4.7.3.4 Crossover Locations

Should powered crossovers be provided, complete with power operated switches and associated block signals as discussed in Section 4.7.1, communication facilities will be required between each local logic controller and the main data centre, through the fibre optic backbone. In addition, separate connectivity may be required between adjacent crossover locations to allow peer to peer communication between logic controllers.

4.7.4 CCTV and Security

A Closed Circuit Television (CCTV) system is necessary to address the safety and security requirements of the streetcar system, while also providing functionality to support the operations and maintenance of the system.

The safety and security requirements are typically defined through a threat and vulnerability analysis by which, in collaboration with security personnel, police services, and operations personnel, the CCTV performance requirements are developed. These requirements must comply with the Freedom of Information and Protection of Privacy Act (FOIPPA).

Selection of CCTV equipment should reference the APTA recommended practice APTA IT-CCTV-RP-001-11 (latest revision), which provides guidelines for the selection of cameras, digital recording equipment and digital high-speed trainlines for use in transit-related CCTV applications.

All CCTV video footage must be recorded, with the ability for only authorized personnel to playback and download recorded images. Tight security measures are required to ensure no access is obtained by unauthorized personnel. All CCTV video imagery must be recorded and stored with encryption, and all recorded images must be watermarked and protected against alterations.

All recordings should be retained for a minimum of 72 hours after which the recordings will be destroyed or over-written automatically unless retrieved for an incident investigation.

As a minimum, CCTV coverage should include the following:

- Platforms, including dedicated cameras to monitor trains arriving at and departing from a stop;
- Shelters at stops;
- Fare equipment and automatic vending machines;
- Emergency phones; and
- Equipment cabinets and buildings housing critical infrastructure.

The CCTV system should be capable of providing simultaneous viewing, recording, and playback. The CCTV camera should automatically start recording by activation of a:

- Fire alarm panel;
- Intrusion detection alarm;
- Access control alarm; or
- Passenger emergency telephone.

Point, Tilt and Zoom (PTZ) cameras should be limited to areas that do not require continuous surveillance. Any PTZ camera in public areas should revert back to a default viewing position and zoom factor after a configurable time.

The use of video analytics, providing features such as facial recognition and guideway intrusion detection, will become more prominent as the technology develops and the need increases for protecting against terrorism and other threats to the public.

Centralized monitoring of the CCTV system may be performed at the control centre and/or separate central security facility. So as to provide sufficient data bandwidth to allow monitoring of multiple camera views, high speed communication infrastructure is required between all field camera locations and the central facilities. This will drive the primary capacity requirements of the fibre optic backbone described in Section 4.7.3, which must be designed with sufficient bandwidth and capacity to simultaneously record all camera outputs at maximum frame rate without any degradation in picture quality and resolution without any loss of data.

In the event of a power outage, CCTV equipment, and all associated backbone communications infrastructure, must remain operational for a minimum period (typically 4 to 8 hours).

4.8 Utilities

There are several common utility design criteria that must be developed on a streetcar system. These include criteria for underground and overhead utilities crossing the streetcar track and running parallel to the tracks.

A utilities exclusion corridor is typically specified which excludes parallel utilities from a zone under the trackway. The preferred situation would be that all utilities running parallel to the tracks within this zone would need to be relocated as maintenance would be severely impactful to operations.

For overhead utilities consideration for the OCS and its electrical isolation is needed.

On NEFC, utilities design criteria were investigated on five other North American low-floor streetcar systems. From this investigation and with consideration of the space available along Pacific Boulevard, the following design criteria was proposed and used in design development.

Table 4-3 Utilities Design Parameters

Parameter	Proposed Criteria
Underground minimum depth	Underground utilities shall cross the streetcar alignment at a minimum depth of 1.00 m from the NEFC design top of asphalt.
Casings	Casing for underground utilities shall not be a NEFC project requirement. If a third party utility wishes to install a casing, then that casing shall extend to 2.0-m each side of nearest track centerline.
Crossing angle	All streetcar alignment crossings (overhead and underground) shall be made at an angle close to the 70-90 degrees range.
Longitudinal	Utilities parallel to the streetcar alignment shall be a minimum of 2.0 m clear of nearest track centerline.
Manholes, etc.	Manholes, vaults, cathodic test pits and/or access hatches shall be located a minimum 2.0 m from the nearest track centerline.
Overhead clearance	No additional provisions for a future overhead contact system will be required as part of the NEFC project requirements.

On other systems it is preferred to provide an exclusion zone that extends 4 m outside of each track centreline in order to provide enough space for excavation without shutting down the streetcar.

In the UK, *Tramway Principles Guidance, January 2018* notes that public utilities in or under the transitway should, where possible, be accessible while streetcars are operating. Any access covers should have their nearest edge at least 500 mm from the edge of the SE. Where pipes and cables have to pass under the track, they should be ducted or sleeved before the tracks are laid, to facilitate maintenance or renewal.

5 Design Guidelines

This section summarizes the key design parameters that will be used to guide the development of the concept designs investigated through the Feasibility Study. A full design guide for a streetcar or LRT project would go into more depth – and will need to be developed in a future design stage, typically functional planning or reference concept – but these criteria are sufficient for the current stage.

The design parameters outlined in the following tables have been developed through consideration of best practices and key reference documents outlined in Section 2.7, and precedent study parameters. They include design parameters presented throughout Section 1 as well as other design parameters that will be used in the Feasibility Study. These parameters include minimum clearances required from the streetcar to structures and property lines, as well as buffer space to traffic lanes, pedestrian walkways, and bicycle pathways.

While the streetcar parameters set out are reasonably conservative, there are only minor adjustments that may be made as the design is refined. The major space requirements are all set and must be accommodated by compromising other more flexible elements of the streets if necessary.

Ultimately many of the assumptions set out will inform the costing exercise to be undertaken later in the project even if they are not utilized directly during the feasibility study.

Streetcar Vehicles Parameter	Proposed Criteria	Comments
Vehicle Type	Full low floor	Modular type
Streetcar Length	30 m	Nominal 30 m length. Note 30 m is a nominal value, some model variants may be longer (e.g. 32.8 m). NEFC and AGP assumed 35 m long platforms
Streetcar Height	3.3 – 3.8 m	Range from Top of Rail to top of roof
Minimum Vehicle Ground Clearance	50 mm – 80 mm	Range from Top of Rail
Streetcar Width	2.65 m	Overall body width, excluding external mounted mirrors or cameras Standard width for vehicles supplied by most manufacturers. 2.4 m vehicles are also common but impose capacity constraints
Vehicle Width at door threshold	2.65 m	Will define platform edge requirements. Note: Width at door threshold height is likely to vary between vehicle models
Door Threshold Height	350 mm	Indicative door threshold height based on a 300 mm platform height and a +/- 50 mm LRV door threshold height
Track Gauge	1435 mm	Nominal
Axle Centres	1800 mm	Typical
Wheel Profile width	105 -115 mm	Typical for on-street types, but may vary
Bogie Configuration	3	Typical, configuration depends on chosen vehicle (2 x motor and 1 x trailer bogies)

Streetcar Vehicles

Parameter	Proposed Criteria	Comments
Maximum Axle Load at $6p/m^2$	<12T	Indicative maximum value based upon the majority of 30 m vehicles available.
Vehicle Coupling	Retractable Auto-Couplers	Assumed to be for coupled operational service. Retractable auto-couplers to be specified to allow 2 x 30 m (nominal) vehicle consist formations. However, if coupling is not required for service then manual couplers can be used which would be for emergency recovery use only.
Passenger Capacity	200+ at $4p/m^2$	The overall passenger capacity will ultimately be dependent upon the type of interior layout chosen (seating vs standing ratio)
Swept Envelope (SE) Width – Straight Track	3.3 m	Considered a conservative assumption which allows for a range of vehicles and will allow for some shallower curves without additional widening
Swept Envelope (SE) Width – Curved Track	Varies	Depending on the radius of curve a minimum in-swing and out-swing will need to be accounted for. The effect of superelevation will need to be considered on the inside of curves. For simplicity, the effects can be assumed to add twice the applied superelevation to the in-swing of the vehicle.
Pantograph Operating Range	4.0 – 6.6 m	Above Top of Rail (TOR). But may need to be higher if there are any specific high-load routes on the alignment

Track Alignment

Parameter	Proposed Criteria	Comments
Absolute Minimum Horizontal Curve Radius	25 m absolute	Although it maybe possible to acquire vehicles capable of tighter radii, 25 m is considered achievable by most modern streetcars.
Desirable Minimum Horizontal Curve Radius	150 m	Reduced speed required with radii less than 150 m. Upper range on minimums preserves for larger range of streetcar technologies
Length of horizontal curves	Greater of 0.57 V or 15 m	The design requirements are speed dependent and should be optimized based on the vehicle performance and the attainable operating speed. V = design speed, km/h
Desirable minimum length of spiral transition	20 m	
Absolute minimum length of spiral transition	10 m	
Desirable minimum length of tangent between reverse spiral curves and	Greater of 0.57 V or 15 m	The design requirements are speed dependent and should be optimized based on the vehicle performance and the attainable operating speed. V = design speed, km/h

Track Alignment

Parameter	Proposed Criteria	Comments
reverse circular curves		
Absolute minimum length of tangent between reverse spiral curves	0 m	The spiral curves and the curve radii are in a desirable range to minimize the twisting effect induced to the coupler of the vehicle. This is not good practice and should not be used unless it can be justified
Minimum vertical curve radius	K = 5 (500 m)	The "K" value defines the rate of change in vertical curves for parabolic curves Typical parameters adopted by other systems
Desirable minimum vertical curve radius in areas of superelevation gradient	K = 20 (2000 m)	
Absolute Minimum length of vertical crest curves	Greater of 0.57 V or 15 m or $AV^2/215$	A = the algebraic difference of the connected gradients, in percentages V = design speed, km/h
Absolute Minimum length of vertical sag curves	Greater of 0.57 V or 15 m or $AV^2/387$	A = the algebraic difference of the connected gradients, in percentages V = design speed, km/h
Minimum length of vertical grades	Greater of 0.57 V or 15 m	
Maximum Gradient	6% preferred 10% absolute	6% is recommended in TCRP 155 but previous market research and project experience has shown that manufacturers will supply vehicles capable of 8% gradients. APTAs Modern Streetcar identified that sustained gradient over 9% are problematic but there are many systems which currently operate on 10% gradients. And as noted in Section 3.1.2.2, vehicles capable of 10% or higher will likely come with an increased cost
Track Centres with centre OCS	4.5 m preferred 4.14 m minimum	
Track centres without OCS or with side OCS	3.63 m preferred 3.5 m minimum	TCRP 155 specifies minimum clearance to adjacent LRT vehicles of 150 mm.
Crossfall	0-2%	Tracks should ideally be at 0%, 1% max if curbside and drainage needs to be maintained. Zero cross slope at special track locations and platforms is good industry practice, the former for constructability and maintenance considerations, the latter to achieve level boarding in order to meet accessibility requirements.
Crossfall Transition Gradient	1:400	

Operations

Parameter	Proposed Criteria	Comments
Typical Operating Speed	30 – 50 km/h	Design speed of the streetcar will generally depend on the road classification, adjacent parking lanes, proximity to parks and school, and sightline issues. This will be further analyzed as the project progresses.
Maximum Design Speed	70 km/h	Many manufacturers will supply vehicles capable 80 km/h or higher May be a requirement for 80 km/h in order to future proof the vehicles for future extensions to the system
Maximum Acceleration Rate	1.2 m/s^2	The full acceleration rate shall be available in the speed range of 0-32 km/h
Average Acceleration Rate	0.866 m/s^2	Value used for run-time calculations
Minimum Deceleration (Service Brake) Rate	1.2 m/s^2	In accordance with EN 13452-1:2003, part 6
Minimum Deceleration (Emergency Brake) Rate	2.8 m/s^2	Emergency Brake is revocable Hazard braking (this is based on the EN 13452 standard for 'Emergency 3' level)
Minimum Dwell time at stop	20 seconds	

Stops

Parameter	Proposed Criteria	Comments
Platform Length	35 m	Consistent with NEFC assumptions and allows for a wide range of vehicles which are nominally categorized as 30 m but can be slightly longer. Would also allow 40 m LRVs to be used as long as the doors are set greater than 2.5 m from each end and other infrastructure is sufficiently distant from the end of the platform.
Clear space on loading edge of platform	1.5 m	Sufficient to allow for a wheelchair passenger movement.
Platform Width – Side	3 m preferred 2.5 m absolute	Consistent with NEFC. 2.5 m is the absolute minimum required to accommodate items such as ticket machines and shelters, and allow circulation on the loading edge. Could potentially be combined with adjacent sidewalk as long as sufficient clear space (1.5 m) is maintained along the loading edge and platform sized to accommodate ridership and pedestrian flows.
Platform Width - Centre	6 m preferred 4 m absolute	4 m is the minimum required in order to accommodate items such as ticket machines and shelters and allow circulation on each side.
Platform Height	300-350 mm	Typical height above top of rail for modern streetcars
Horizontal platform gap	50 mm	
Track centre to platform edge	1375 mm	
Length of tangent beyond platform ends	10 m	
Platform Gradient	2%	Derived from ADA regulations and consistent with TransLink requirements for platforms on rail based systems
Ramp length	6.0 m preferred (1 in 20) 3.6 m minimum (1 in 15)	

Clearances

Parameter	Proposed Criteria	Comments
Between two streetcars DEs without centre OCS poles	200 mm	TCRP 155
Between two streetcars DEs with centre OCS poles	800 mm With at least 150 mm to the face of the pole	Most poles will typically be less than 500 mm but occasional ones may need to be larger
Isolated Obstruction – Clearance to Swept Envelope	600 mm preferred 100 mm absolute	The absolute minimum should only be considered in locations where streetcar is segregated and pedestrian access is restricted
Continuous Obstruction – Clearance to Swept Envelope	1000 mm preferred 600 mm absolute	This will be further analyzed as the alignment adjacencies and conflicts are investigated.
Edge of pedestrian walkway or bicycle pathway – Clearance to Swept Envelope	600 mm preferred 400 mm absolute	This will be further analyzed as the alignment adjacencies and conflicts are investigated.
Shyway from streetcar SE to adjacent traffic if segregated	300 mm	Minimum width of curb and cutter
Distance to edge of traffic lane if shared running	100 mm	Allowance to avoid any conflicts between streetcar SE and vehicle in adjacent lane

Streets Parameter	Proposed Criteria	Comments
Standard Travel Curbside Lane Width	3.4 – 3.5 m	Future streetcar shall be accommodated mostly in the curb lanes with a future curb lane width of 3.5 m, attained by slight reductions in adjacent thru lanes (either to 3.0 or 3.05 m). Additional widening of lanes around curves shall be dictated by turning envelope of design vehicle.
Standard Travel Lane Width (non-transit, non-truck route)	3.3 m	
Turn Lane Width	3.3 m	
Parking Lane width	2.5 m	
Sidewalk		Measured from face of curb or edge of boulevard to back of sidewalk
Commercial Areas	2.4 m	
Other	1.8 m	
Boulevard/furnishing zone	1.5 m	Measured from face of curb
Bicycle Lane		
Unidirectional	2.5 m	
Bidirectional	3.0 m	
Buffer	1.0 m	
Multi-Use Paths	3.0 m	
Minimum unobstructed width for fire trucks	6 m	Allows for large fire trucks (ladder trucks) to put out stabilizing outriggers

Traction Power

Parameter	Proposed Criteria	Comments
TPSS Spacing	n + 1 (Distance TBD)	Load flow analysis to confirm operational resiliency to allow system to operate under single TPSS failure mode scenario. Cost/benefit analysis to determine whether typical LRT or streetcar spacing is most appropriate given Vancouver's high real estate values.
Utility Services	Single Utility Feed	Subject to adjacent TPSS locations fed from separate utility substations. Endeavour to design for residential utility feed rather than primary feed.
Utility Service Redundancy	Fully Diverse	No two adjacent TPSS locations to be fed from same utility substation.
Nominal Operating Voltage	750 V DC	Greater predominance and allows greater variety for vehicle selection.
No Load Voltage	900 V DC	Above nominal voltage level, the tractive effort versus speed characteristic shall not vary as a function of catenary voltage
Minimal Voltage	525 V DC	Below nominal voltage, the speed to which the full acceleration rate is maintained shall decrease in direct proportion to the reduction in catenary voltage
Maximum Voltage	1000 V DC	Due to Regeneration
Maximum Current Per Car	1500 A	
Auxiliary Standing Load	60 – 100 kW	Range varies depending upon vehicle type and any specific requirements (e.g. air conditioning)
TPSS Sizing	0.5 MVA	Smaller TPSS allows less OCS infrastructure and smaller TPSS footprint.
TPSS Enclosure	Pre-fabricated	Lower cost and smaller footprint.
TPSS Location	Max 100 m from track	Minimize losses and EMF effects
OCS	Single Contact Wire, Simply Suspended	Avoid parallel messengers, if required bury parallel feeders
Minimum OCS height in roadway	5.8 m	In roadway areas with road traffic (e.g. intersections and in-street shared running)
Minimum OCS height off-road	4.0 m	In areas where there is no pedestrian or roadway traffic.
Maximum OCS Stagger	+/- 300 mm	Either side of track centre line

Systems

Parameter	Proposed Criteria	Comments
Signalling (Clear Sightlines)	Line of Sight	
Signalling (Restricted Sightlines)	Automatic Block Signalling	Consider also for reverse running
Switch Point Protection	Detector Locking (Mass Detectors)	Protection against inadvertent switch throw
Central Control System	Integrated System (Train Routing, SCADA, Building Management, Public Address, HMI)	Forward looking technology
Communication Backbone	Fibre Optic Cabling in U/G Duct Bank	Cable system to extend horizontally along the alignment
Communications	IP, with PoE End Devices Where Practical	Minimizes cabling and power requirements
CCTV	APTA IT-CCTV-RP-001-11	Privacy requirements also to be compliant with FOIPPA
CCTV Recording Retention	72 Hours	
Stop Infrastructure	Passenger Wifi, CCTV Cameras, Emergency Telephones, Fare Collection, Public Address and Variable Messaging Signs	All end devices IP, PoE fed from platform mounted IP switches

Utilities

Parameter	Proposed Criteria
Underground minimum depth	Underground utilities shall cross the streetcar alignment at a minimum depth of 1.00 m from the design top of asphalt.
Casings	Casing for underground utilities shall not be a project requirement. If a third party utility wishes to install a casing, then that casing shall extend to 2.0 m each side of nearest track centerline.
Crossing angle	All streetcar alignment crossings (overhead and underground) shall be made at an angle close to the 70-90 degrees range.
Longitudinal	Utilities parallel to the streetcar alignment shall be a minimum of 2.0 m clear of nearest track centerline.
Manholes, etc.	Manholes, vaults, cathodic test pits and/or access hatches shall be located a minimum 2.0 m from the nearest track centerline.
Overhead clearance	No additional provisions for a future overhead contact system will be required as part of the project requirements.

Appendices

A. 388583-MMD-00-P0-MO-TR-0001 – Background Document Review Memo

Appendix A 388583-MMD-00-P0-MO-TR-0001 – Background Document Review Memo

Subject	Background Document Review
To	City of Vancouver Project Team
From	Mott MacDonald Canada Limited – Prepared by Katherine Miller *Checked by Elicia Elliott and Reviewed by Gary Farmer*
Our reference	388583-MMD-00-P0-MO-TR-0001
Date	August 16, 2018 – Rev C

The City of Vancouver has been contemplating the development of a modern streetcar network since the 1990s, following the decommissioning of its original streetcar network through the 1950s. Contemplation of the reimagined network began in the mid-1990s when the City purchased a segment of former rail right-of-way between Granville Island and Cambie Street from CP Rail – what would later become the Downtown Historic Railway (DHR) in 1998 and the Olympic Demonstration Streetcar in 2010. Steps toward realizing a modern network have continued via the City preserving right-of-way both on- and off- street as development and street reconstruction has occurred, the City purchasing the Arbutus corridor from CP Rail in 2016, and the City undertaking several studies for part or all of the proposed network.

The City of Vancouver has engaged Mott MacDonald to build upon the wealth of previous work, and to imagine Vancouver's streetcar future by incorporating the latest technology trends, planning visions for different areas and City policies into a feasibility study. This will be done by reviewing previous work, current City plans and policies, and industry best practices. These reviews will form the foundation for the development of Streetcar Design Considerations Report. From these a Feasibility Study will be undertaken. It will involve reviewing and updating the streetcar routing, incorporating additional technical detail, contemplating alignments given existing and planned land use scenarios, developing a high level ridership forecast, preparing capital cost estimate, benchmarking typical operating costs, and outlining potential funding mechanisms, business case requirements and project next steps. The study will be used by the City as a planning tool to continue to secure space for a future streetcar, enhance multimodal integration, and identify constraints and confirm network design.

This memo provides an overview of previous studies including pertinent network routing information, details different earlier cross-sectional assumptions and design parameters, and identifies out-of-date assumptions.

Network Routing History

One of the primary elements that has been developed and carried through the past work is the streetcar network routing. Over time and the various studies, the proposed downtown streetcar network has evolved and been refined.

Routing maps from the 1990s looked to the historical British Columbia Electric Railway Company Limited streetcar network, which was phased out during the “Rails to Rubber” campaign in the 1940s and 1950s. One of the 1990s network maps is from the 1997 Downtown Streetcar Study by Baker McGarva Hart, SNC Lavalin and Ward Consulting (aka the “BSW Report”), as shown in Figure 1. This map illustrates some of the 13 alignment networks and subsets that were modelled and evaluated. It showcases the two recommended base options: from Granville Island to Science World then on to either Waterfront Skytrain Station (Option 1) or the Yaletown Roundhouse located in North False creek (Option 2).

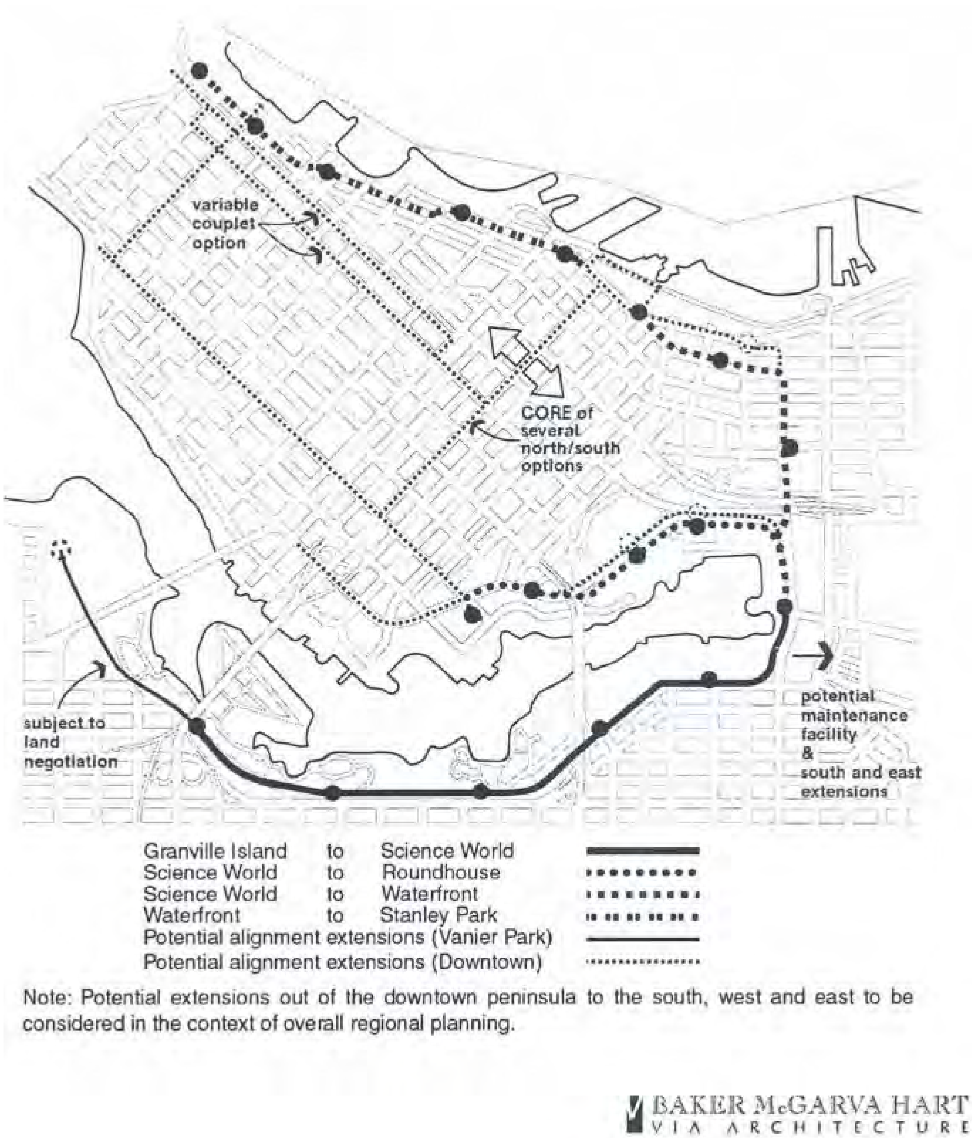

Figure 1 Downtown Streetcar Network Routing from BSW Report, 1997

Following the 1997 BSW Report and extensive public consultation, Vancouver City Council approved a concept plan for a streetcar system in 1999. The approved and potential streetcar routes can be seen in Figure 2, and include routes on Granville Street and Granville Bridge.

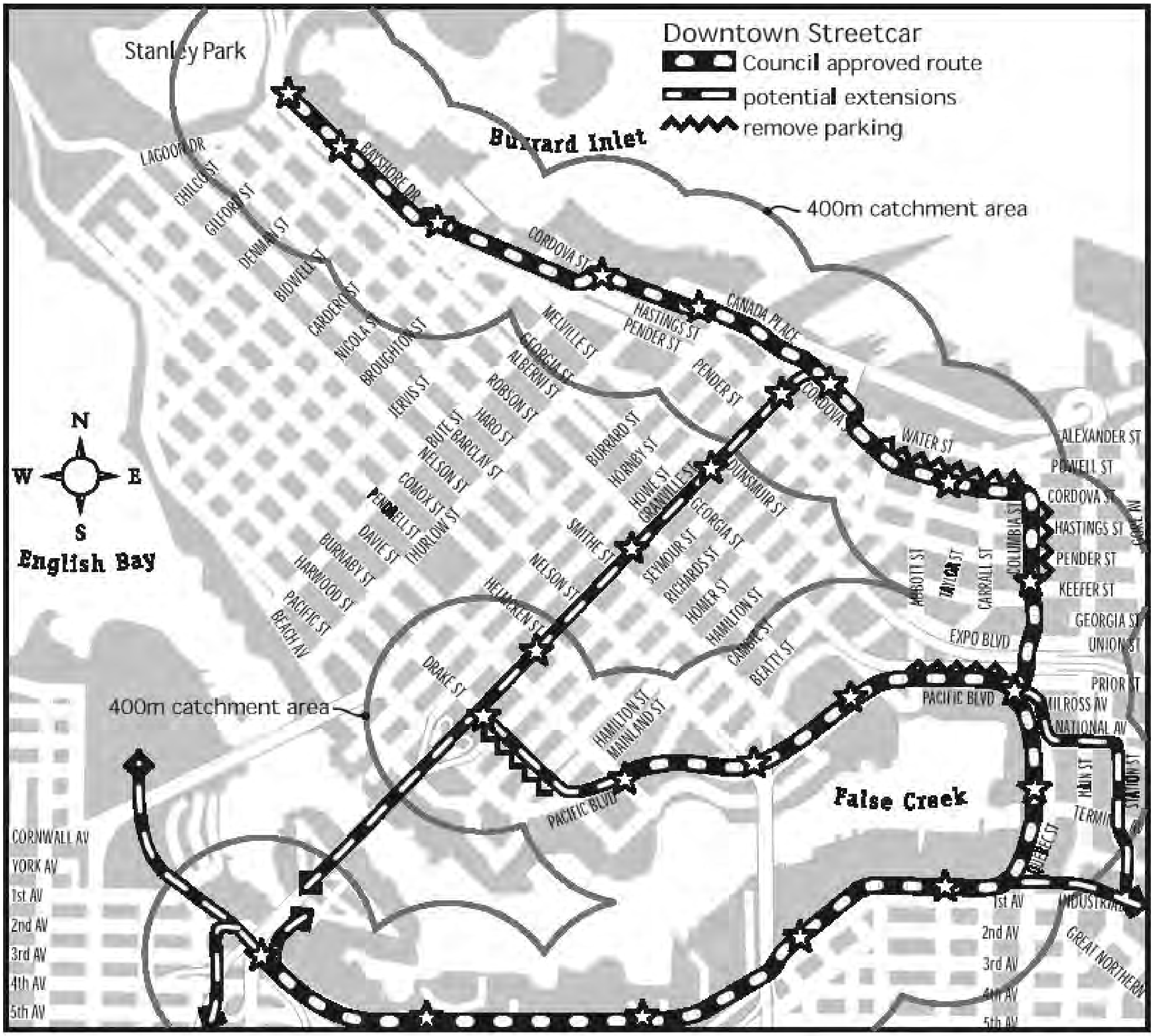

Figure 2 1999 Council Approved and Potential Streetcar Routes

Figure 3 Downtown Streetcar from Downtown Transportation Plan, 2002

Then in 2002 the Downtown Transportation Plan made recommendations to adjust the Downtown Streetcar to integrate the recommended changes in the Downtown Transportation Plan. This included terminating the Pacific Boulevard Line on Drake Street at Granville Street and consideration for double tracking through Gastown by siting a segregated track on Cordova Street in addition to a track on Water Street. This is reflected in the adjacent Figure 3.

These recommendations were carried forward in the 2005 Downtown Streetcar Design, Layout and Ridership Study by IBI in 2005 which focused on the development and refinement of a specific alignment from Granville Island to Waterfront Station, known as Phase I.

Then the project update identified a strategic opportunity to stage the implementation in more manageable components beginning with a 'Phase 0' section from Granville Island to Science World. This updated, and most current proposed routing for the Downtown Streetcar and connection to the Arbutus Greenway can be seen in Figure 4. The Arbutus streetcar route is being considered as a part of the Arbutus Greenway Project, which is a master planning exercise for the Arbutus corridor which the City purchased from CP Rail in 2016.

Figure 4 Current Proposed Streetcar Routing

Review of Background Documents

The following section includes brief summaries of the background documents that were provided to the consultant team, and documents from the Northeast False Creek Project (NEFC) and Arbutus Greenway Project (AGP) which are current city projects that safeguard for a future streetcar system. This review will lay the groundwork for Design Guidelines, Streetcar Principles and Feasibility Study.

PPP Review of Vancouver Streetcar Project (Macquarie North America, 2002)

The report is to advance the understanding of public private partnership (PPP) funding and delivery strategies as a possible means of developing the streetcar. It reviewed past work such as the BSW Report. It specifically focused its review on ridership and capital and operating cost assumptions.

Key findings include:

- The project could be delivered as a PPP given its “self-contained” nature and its high expected ridership;
- Funding and operating arrangements with government and TransLink need to be established before engaging the private sector; and
- Further analysis around ridership, project definition, phasing options, corridor selection and engineering specification is necessary for the project to proceed.

Ridership

The PPP Report went in-depth into sources of risk and methodology for ridership forecasts. It also outlined that further review of comparable systems and market research on origin/destination and stated preference was needed.

Downtown Streetcar Benchmarking Report (2004)

In 2004, the City of Vancouver commissioned a review of streetcar and light rail systems, both restored historic and modern urban transit systems, from around the world. The exercise was intended to provide information on the characteristics of streetcar systems that might be applicable in the Downtown Vancouver Streetcar context.

Results from the review include:

- The extent to which systems have priority over the other traffic is important and almost all systems reviewed have some segregated running sections
- New streetcar systems have been built with platforms that allow for universal accessibility, primarily easy wheelchair access. Stop spacing varies from 1-2 blocks up to 1-2 km apart. Stops are typically further apart on dedicated alignments where there is a speed advantage to longer spacing, and closer together in downtown areas to maximize coverage.
- Peak services typically operate between 6 – 10 minute headways and off-peak services are generally half the frequency of peak periods.

- The systems reviewed have healthy ridership level proportional to their size and transit coverage and in some cases demand has exceeded initial expectations.

Tourist and Recreational Usage of Proposed Downtown Streetcar (2004)

The City of Vancouver commissioned a study of tourist and recreational usage in the summer of 2004 to gauge the interest of visitors and local residents on their likelihood of using the Downtown Streetcar. It revealed that the streetcar concept had significant support among those who visit the downtown, and that as planned, it would serve desired destinations. Its attractiveness would be reliant on its frequency and integration with the rest of the transit network.

The study highlighted the following key opinions/recommendations from those surveyed:

- Streetcar fares and pricing should be integrated with the whole public transit network;
- The type of streetcar (modern versus historic styling) is not a key factor;
- Tourists and residents agreed that the top destinations are Stanley Park and Granville Island, but there was more enthusiasm and commitment from tourists about using the streetcar; and
- Service frequency should be approximately 10-minute intervals or less.

Downtown Streetcar Design, Layout, and Ridership Study (IBI Group, 2005)

This report discussed the City of Vancouver's overall vision of the Downtown Streetcar, defining its alignment, stops, projected ridership, revenue, and cost estimates. It examined alternative track alignment and stop location options for the Phase 1 route from Granville Island to Waterfront Station.

The evaluation used both qualitative and quantitative criteria to assess the developed options and recommend a preferred solution. The preferred streetcar design concept is generally segregated from traffic from Granville Island to Pacific Boulevard (see Figure 5 and Figure 6), a combination of segregation and mixed on-street traffic on Columbia Street (see Figure 7 and Figure 8), and mixed with traffic east/west along Cordova Street and Water Street respectively (see Figure 9).

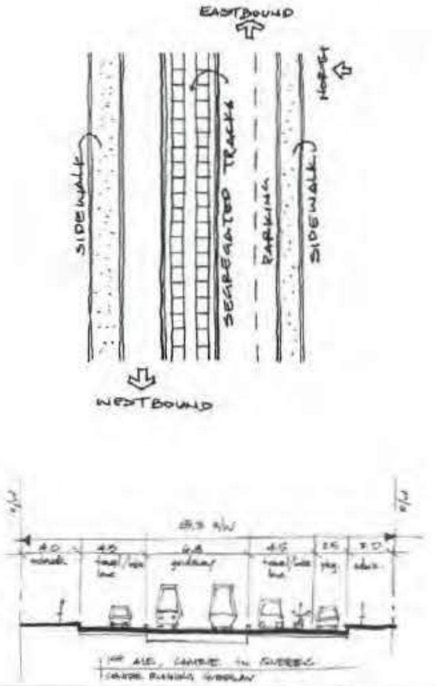

Figure 5 Southeast False Creek – Centre Running Streetcar Option

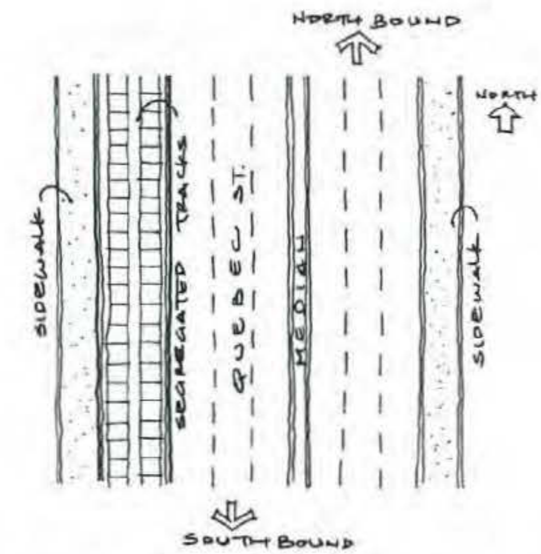

Figure 6 Quebec Street: 1st Avenue to Pacific Boulevard – West Side Running Streetcar Option

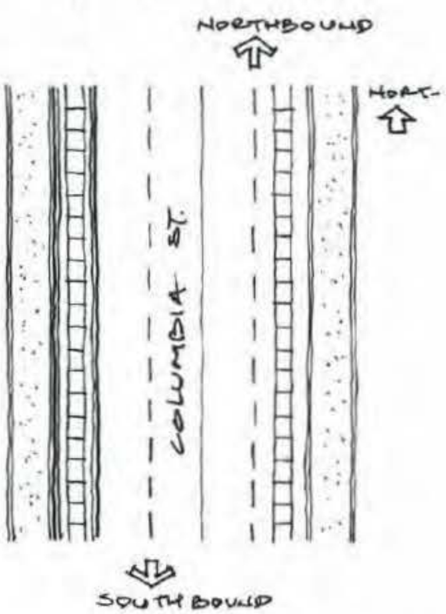

Figure 7 Quebec Street: Pacific Boulevard to Keefer Street - Split Running Streetcar Option

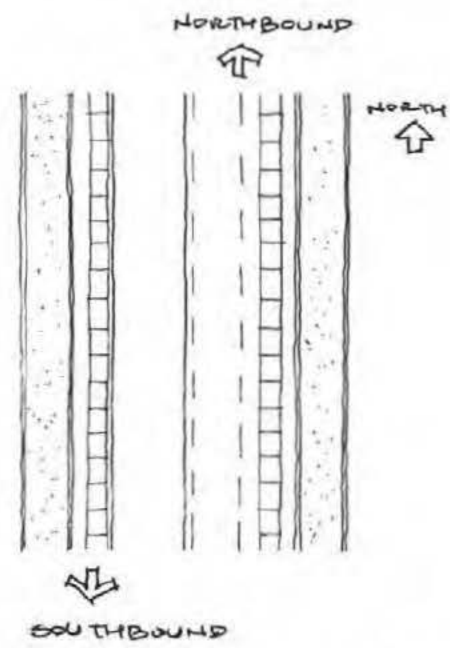

Figure 8 Columbia Street: Keefer Street to Cordova Street - Split Running Streetcar Option

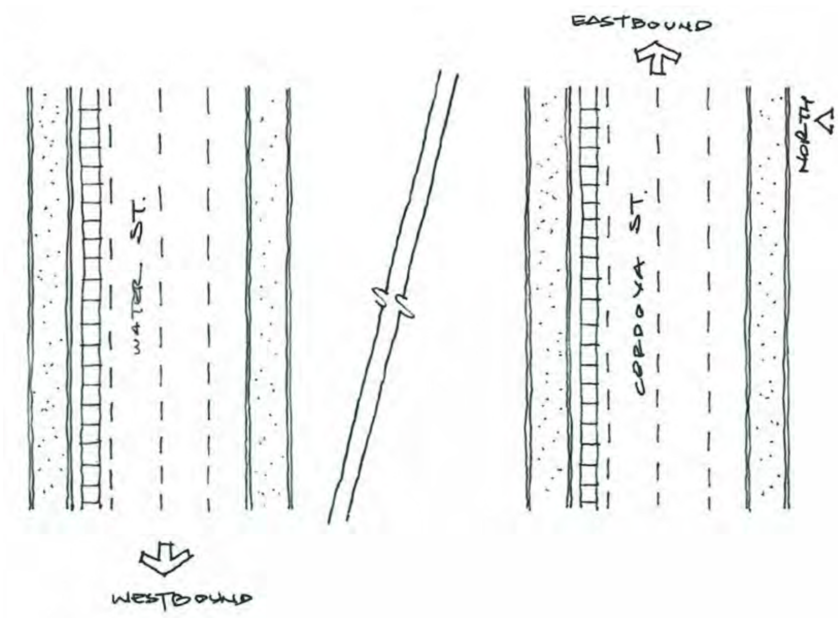

Figure 9 Gastown: Cordova Street and Water Street - Streetcar Couplet

To develop the above options the following basic parameters, which were explicitly laid out in the report, were used:

- Track gauge = 1.435m (standard);
- Distance between track centres on a double track section = 4.120m;
- Total guideway width on a double track section = 7.0m preferred (6.8m along 1st Avenue);
- Minimum curve radius = 18.3m, preferred radius = 25.0m;
- Standard traffic lane = 3.6m; left turn (traffic) lane 3.0m;
- Traffic lane with bicycle lane = 4.0m (minimum);
- Parking lane = 2.5m; and
- Stop location is dependent on the opportunity to serve surrounding land uses but as a general rule, the streetcar stop spacing is 200 m to 400 m. (This is approximately the spacing of two to four city blocks.);

Figure 10 was included to show the breakdown of cross-section elements for a double-track section.

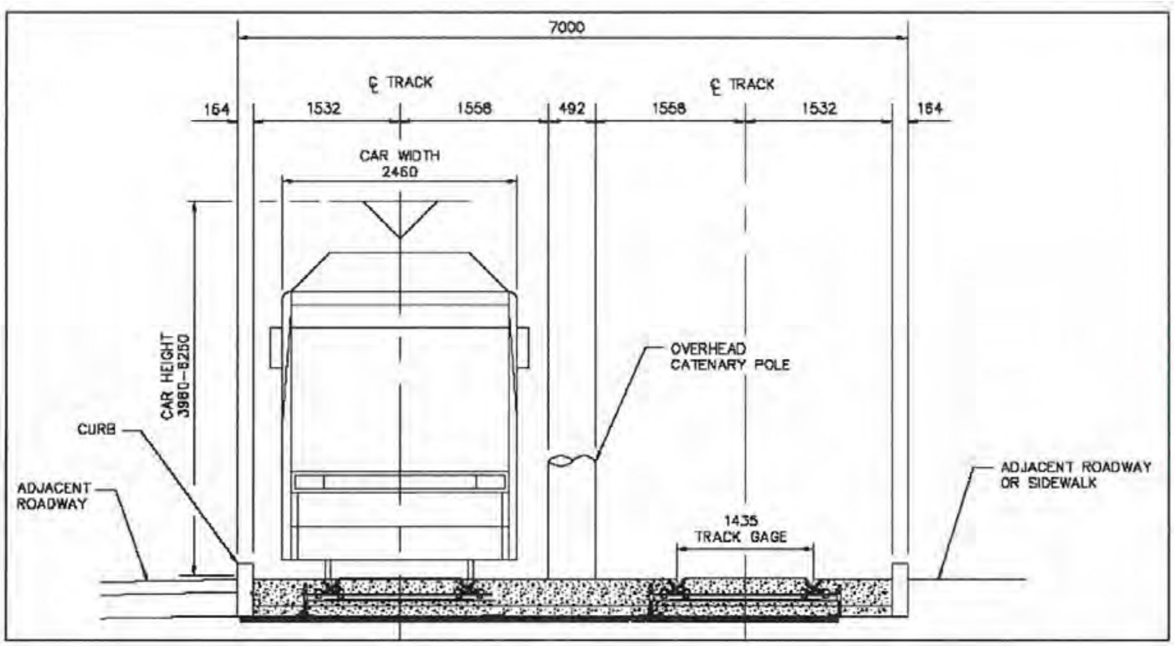

Figure 10 Typical Streetcar Cross-Section Dimensions from 2005 IBI Streetcar Study

Maintenance Facility

The requirements for a streetcar operations and maintenance facility (OMF) were also investigated. Building a facility along the Phase 1 route sufficient to support the initial line is identified as critical, as is developing an OMF that can adapt to the maintenance needs of the streetcar system as it grows.

The 2005 IBI Study noted initial fleet size estimates are from 6 – 15 vehicles for the Downtown Streetcar network, including Phase I and the Stanley Park and Pacific Boulevard extensions. Based on the fleet size it made recommendations for site size (minimum of 2.5 acres) and technical efforts were focused on the 800 Quebec Street lot, under the Georgia and Dunsmuir viaducts.

Ridership

In 2004 a market research exercise was conducted. Based on this exercise, the tourist and recreational trips for the 2005 Study were estimated. These are now considered outdated because of updates to TransLink's Regional Transportation Model (RTM) and the growth Vancouver and the Lower Mainland has seen over the intervening period.

Outdated Assumptions

While the technical parameters for vehicle design included in this study are now considered outdated due to advancements in technology, the Study does provide some useful context, highlighting the City of Vancouver's vision for streetcar, where streetcar service is "intended to provide an attractive transit service in developing areas, linking destinations, and serving combined usage by residents, workers, and tourists".

Additionally, the assumptions for the maintenance facility including fleet size, site and shop size, and location will need to be revisited as a part of this Feasibility Study. As a part of the NEFC project, the Georgia and Dunsmuir viaducts will be removed, a new complete street network implemented and several sites redeveloped. The 800 Quebec Street lot is proposed to be redeveloped into a mixed-use development and is a cornerstone in reconnecting Main Street, Chinatown and the communities to the south. Thus, the streetcar maintenance facility will need to be located elsewhere.

This document was the last major study of the complete Downtown Streetcar Project.

Streetcar and Local Bus Comparative Review (IBI, 2006)

This was a comparative memorandum that looked at the financial, operational, traffic and social impacts and characteristics of streetcars and local bus services, as well as at the specific characteristics of the proposed Downtown Streetcar. This comparative review found the following:

- Streetcars have higher initial capital costs but this can be offset through additional ridership/passenger revenue and operating cost savings from integrated service;
- Streetcars with a dedicated right-of-way can run at higher average speeds, offer greater reliability and capacity than local buses in mixed traffic; and
- Streetcar has more presence than a bus route and can act as a redevelopment stimulus, as well as enhance urban design and streetscapes.

Overall, there are numerous transit operations, personal mobility, urban environment and economic spin-off benefits from a streetcar service that support its implementation in a well-chosen corridor.

Downtown Streetcar Project – Preliminary Design Report (Hatch Mott MacDonald, 2008)

This 2008 report examined a streetcar design along the Southeast False Creek (SEFC) area from Granville Island to Science World, which was previously defined as Phase 0 in the IBI 2005 report and a City staff report in October 2006. These previous reports formed the basis upon which the preliminary design was developed.

The preliminary engineering confirmed the definition of a generic 2.46m wide modern streetcar vehicle upon which preliminary design could be based and how this would interact with the DHR vehicles and infrastructure. The required right-of-way was defined by the vehicle dimensions. From this it was determined that a 6.9m ROW which was based on the 2006 IBI study needed to be amended to accommodate a double track streetcar system. An absolute minimum median of 7.1m was recommended for 1st Avenue, with a maximum 8.4m ROW in some areas where there were track curves.

The report went on to outline findings and requirements for traction power, track form, traffic and LRT signals, utilities, stops and urban design, maintenance yard, operations, cost estimate and risk registry.

Overall, the findings and deign parameters from this report will need to be revisited because the latest vision for streetcar does not include the requirement for incorporating heritage vehicles and the DHR. However, it does provide insights into technical considerations and requirements that will need to be carried forward.

Central Waterfront Hub Framework (2009)

The Waterfront Hub Framework outlines a vision for the creation of a world-class transportation interchange. It identifies and explores some significant challenges facing development in the area such as complex engineering and technical issues, particularly the impact of development over the Canadian Pacific rail yard, the financial expense of the development, and the coordination of interrelated development between multiple landowners and stakeholders.

In order to develop a variety of streetcar options, recommendations for design parameters were supplied in consultation with Hatch Mott MacDonald. At the time, Hatch Mott MacDonald was the engineering consultants working on the Olympic Demonstration Line.

The outlined streetcar design parameters included:

- Min. optimal turning radius – 50 m
- Min. turning radius – 25 m
- Min. amount of straight track between curves and streetcar station platform -10m
- Anticipated Streetcar length 25 – 35 – 45 m
- Anticipated Streetcar platform length 25 – 35 – 45 m
- Min. streetcar station width - 3.5 m
- Min. shared streetcar/vehicle lane width - 3.5 m
- No switches in intersections

Through option development and evaluation, a 35 m streetcar length was preferred. This was because a shorter 25 m platform was likely insufficient to accommodate typical streetcar vehicle lengths, and 45 m would have significant implications on bike connections and the track turn-around terminus that was included in the design.

These design parameters are applicable in developing and confirming the streetcar geometric design considerations.

Transportation 2040 (2012)

Transportation 2040 is the City of Vancouver's long-term strategic transportation plan that will guide transportation and land use decisions and public investments. It includes high-level policies and specific actions to achieve the vision. One such specific action related to the streetcar network is *T 1.2.5 Advance a Downtown-False Creek-Arbutus streetcar service*, through measures including:

a. protecting rights-of-way and designing streets to accommodate the service; and
b. working with TransLink on a business case.

Additionally, it maintains the City's long-term transportation objective to develop the Arbutus Corridor as a future active transportation greenway and streetcar/light rail line.

Northeast False Creek Plan (NEFC) and Arbutus Greenway Project (AGP)

As a part of implementing Transportation 2040 and continuously cultivating its vision of a streetcar network, the City has advanced several projects, two of which are the Northeast False Creek Plan (NEFC) and Arbutus Greenway Project (AGP). Both of these projects are a part of the contemplated Downtown-False Creek-Arbutus streetcar network, and have included streetcar considerations and principles in their development. The Streetcar Feasibility Study will be conscious of the parameters and considerations these projects have developed and used.

NEFC – Streetcar Considerations Memo (Mott MacDonald, 2016)

The NEFC Streetcar Considerations Memo highlights important streetcar geometric parameters recommended by Mott MacDonald, with reference to TCRP 155: Track Design Handbook for Light Rail Design. This memo provides high-level guidance on streetcar design for the Northeast False Creek Plan. The outlined parameters, such as vehicle dimensions, dynamic envelope, roadway interfaces and power supply, are applicable in developing and confirming the streetcar geometric design considerations, particularly for in-street streetcar concepts.

NEFC – Streetcar Implementation Considerations Memo (WSP | MMM, 2017)

Like the NEFC memo prepared by Mott MacDonald, this document provides some high-level guidance and recommends firm geometric parameters to be used as the NEFC work is progressed. These geometric parameters are summarized in Table 1 of the NEFC Streetcar Implementation Considerations Memo (see attached).

These parameters are currently being adopted on City of Vancouver infrastructure work, so, although the NEFC project is not yet under construction, the assumptions used now will set precedents and guidance for other projects.

AGP – Streetcar Planning & Context Memo (Mott MacDonald, 2017)

The Streetcar Planning & Design Context Memo contextualizes considerations for planning and design of streetcar within the wider interdisciplinary process. The Context Memo includes:

- A brief orientation to streetcar as a modern transit technology
- An overview of modern streetcar considerations taken to-date in the Metro Vancouver context
- A discussion of general design principles, including philosophical and technical considerations

- Considerations for later stages of design, including:
  - Recommendations for streetcar design guidelines
  - Recommended geometric design parameters for streetcar and stops, and futureproofing
- Planning assumptions used in generating schematic concepts for the inclusion of streetcar on the future Arbutus Greenway.

The memo also discusses the multimodal integration (active transportation, streetcar, and general purpose traffic) of the north and south ends of the corridor into the wider Vancouver and regional transit system.

And subsequently the design parameters for the AGP were developed through consideration of best practices and key reference documents, such as the NEFC Streetcar Implementation Considerations Memo.

Ascertaining the City of Vancouver's preferred approach to some of the overarching philosophical design assumptions and challenges described here will inform the development of a preferred concept for the future Arbutus Greenway.

The following table was included in the AGP Streetcar Planning & Context Memo and outlines geometric and clearance design parameters. It also notes any consistencies or conflicts with the NEFC design criteria.

Table 1 Streetcar Design Parameters from AGP

Parameter	Proposed Criteria	Comments
Geometry		
Minimum Radius – Horizontal	25 m	Although it maybe possible to acquire vehicles capable of tighter radii, 25m is considered achievable by most modern streetcars.
Minimum Radius – Vertical	250 m (crest) 250 - 350 m (sag)	Typical parameters adopted by other systems
Maximum Gradient	6% preferred 10% absolute	6% is what is recommended in TCRP 155 but previous market research and project experience has shown that manufacturers will supply vehicles capable of 8% gradients. APTAs Modern Streetcar identified that sustained gradient over 9% are problematic but there are many systems which currently operate on 10% gradients.
Streetcar Length	35 m	Consistent with NEFC assumptions
Streetcar Width	2.65 m	Standard width for vehicles supplied by most manufacturers. 2.4m vehicles are also common but impose capacity constraints
Dynamic Envelope (DE) Width – Straight Track	3.4 m	Considered a conservative assumption which allows for a range of vehicles and will allow for some shallower curves without additional widening
Dynamic Envelope (DE) Width – Curved Track	Varies	Depending on the radius of curve a minimum in-swing and out-swing will need to be accounted for. The effect of superelevation will need to be considered on the inside of curves. For simplicity, the effects can be assumed to add twice the applied superelevation to the in-swing of the vehicle.
Platform Length	35 m	Consistent with NEFC assumptions and allows for a wide range of vehicles which are nominally categorised as 30m but can be slightly longer. Would also allow 40m LRVs to be used as long as the doors are set greater than 2.5m from each end and other infrastructure is sufficiently distant from the end of the platform.
Clear space on loading edge of platform	1.5 m	Sufficient to allow for a wheelchair passenger movement.
Platform Width – Side	3 m preferred 2.5 m absolute	Consistent with NEFC. 2.5 m is the absolute minimum required to accommodate items such as ticket machines and shelters, and allow circulation on the loading edge. Could potentially be combined with adjacent sidewalk as long as sufficient clear space (1.5 m) is maintained along the loading edge and platform sized to accommodate ridership and pedestrian flows.
Platform Width - Centre	5 m preferred 4 m absolute	4m is the minimum required in order to accommodate items such as ticket machines and shelters and allow circulation on each side.
Platform Height	300-350 mm	Typical height above top of rail for modern streetcars
Platform Gradient	2%	Derived from ADA regulations and consistent with TransLink requirements for platforms on rail based systems
Typical Design Speed	30 – 50 km/h	Design speed of the streetcar will generally depend on the road classification, adjacent parking lanes, proximity to parks and school, and sightline issues. This will be further analyzed as the project progresses.
Maximum Design Speed	80 km/h	Many manufacturers will supply vehicles capable 80 km/h or higher
Clearances		
Between two streetcars DEs without centre OCS poles	200 mm	TCRP 155
Between two streetcars DEs with centre OCS poles	800mm	Most poles will typically be less than 500mm but occasional ones may need to be larger

	With at least 150 mm to the face of the pole	
Centreline track to edge of platform	1415mm	
Isolated Obstruction – Clearance to Dynamic Profile (Applies to Tangent and Curved Track)	600 mm preferred 100 mm absolute	The absolute minimum should only be considered in locations where streetcar is segregated and pedestrian are unlikely to be
Continuous Obstruction – Clearance to Dynamic Profile (Applies to Tangent and Curved Track)	1000 mm preferred 600 mm absolute	This will be further analyzed as the alignment adjacencies and conflicts are investigated.
Edge of pedestrian walkway or bicycle pathway – Clearance to Dynamic Profile (Applies to Tangent and Curved Track)	600 mm preferred 400 mm absolute	This will be further analyzed as the alignment adjacencies and conflicts are investigated.

Summary and Next Steps

Overall there is a wealth of previous work on the Vancouver Streetcar Network, particularly the Downtown Streetcar. We will be using this previous work from Vancouver's streetcar history to lay the foundation for the Feasibility Study. The background document review has highlighted the robust work over many years that has gone into the development and refinement of the Vancouver streetcar network, as well as the assumptions and parameters that need to be revisited and updated at this time. The following is summary of the documents that have been reviewed, their key findings which will be utilized going forward, and how other key elements will be carried forward.

Table 2 Background Document Review Summary

Document Name	Key Findings/Notes	Carry forward?		
		Design Parameters	Maintenance Facility	Ridership
PPP Review of Vancouver Streetcar Project *(Macquarie North America, 2002)*	• Project could be delivered as PPP • Funding and operating arrangements to be made with government • Further analysis needed on ridership, Project definition, phasing options, corridor selection and engineering specification			• Use outlined sources of risk and methodology for forecasting as starting point
Downtown Streetcar Benchmarking Report *(2004)*	• Extent of streetcar priority is important and most systems have some segregated running sections • New streetcar system platforms allow for universal accessibility • Stops are spaced further apart on dedicated alignments and closer together in downtown areas to maximize coverage • Peak services typically operate between 6 – 10 minute headways and off-peak services are generally half the frequency of peak periods. • Healthy ridership levels are proportional to system size and transit coverage			
Tourist and Recreational Usage of Proposed Downtown Streetcar *(2004)*	• Streetcar fares and pricing should be integrated with the whole public transit network • The type of streetcar (modern versus historic styling) is not a key factor • Tourists and residents agree that the top destinations are Stanley Park and Granville Island, but there was more enthusiasm and commitment from tourists about using the streetcar • Service frequency should be approximately 10-minute intervals or less			
Downtown Streetcar Design, Layout, and Ridership Study *(IBI Group, 2005)*	• Preferred concept was: – segregated from traffic from Granville Island to Pacific Boulevard – a combination of segregation and mixed on-street traffic on Columbia Street – mixed with traffic east/west along Cordova Street and Water Street respectively	• Require substantial review, as many will be outdated due to advancements in technology as well as right-of-way and operating assumptions	• No, as 800 Quebec Street will be redeveloped as part of NEFC • Assumptions for the maintenance facility including fleet size, site and shop size, and location will need to be revisited	• No, as outdated due to updates to TransLink's RTM
Streetcar and Local Bus Comparative Review *(IBI, 2006)*	• Streetcars have higher initial capital costs but this can be offset through additional ridership/passenger revenue and operating cost savings from integrated service • Streetcars with a dedicated right-of-way can run at higher average speeds, offer greater reliability and capacity than local buses in mixed traffic. • Streetcar has more presence than a bus route and can act as a redevelopment stimulus, as well as enhance urban design and streetscapes			

Document Name	Key Findings/Notes	Carry forward?		
		Design Parameters	Maintenance Facility	Ridership
Downtown Streetcar Project – Preliminary Design Report *(Hatch Mott MacDonald, 2008)*	• Generic 2.46m wide modern streetcar was used • Absolute minimum median of 7.1m was recommended for 1st Avenue, with a maximum 8.4m median/ROW	• No, as latest vision of streetcar network does not include DHR and the "modern streetcar" assumptions will need to be updated to suit more recent Streetcar vehicles • Does provide insights into technical considerations and requirements	• No, utilized 800 Quebec Street which is to be redeveloped as part of NEFC	
Central Waterfront Hob Framework (2009)		• Yes, the parameters are still applicable.		
Transportation 2040 *(2012)*	• Advance a Downtown-False Creek-Arbutus streetcar service, through measures including: – protecting rights-of-way and designing streets to accommodate the service; and – working with TransLink on a business case.			
NEFC – Streetcar Considerations Memo *(Mott MacDonald, 2016)*		• Yes, principles for vehicle dimensions, dynamic envelope, roadway interfaces and power supply		
NEFC – Streetcar Implementation Considerations Memo *(WSP | MMM, 2017)*		• Yes, the parameters are currently being adopted on City of Vancouver infrastructure work		
AGP – Streetcar Planning & Context Memo *(Mott MacDonald, 2017)*	• Will carry forward and build on: – A brief orientation to streetcar as a modern transit technology – the discussion of general design principles, including philosophical and technical considerations – Recommendations for streetcar design guidelines – Recommended geometric design parameters for streetcar and stops, futureproofing	• Yes, consistent with NEFC and being utilized in the development of the AGP Corridor		

The next step in the Feasibility Study will be to develop Design Guidelines. These will include design principles and transit priority guidelines to be used in future streetcar planning and transit concept plans. The design parameters from NEFC and AGP will be utilized and carried forward through the Vancouver Streetcar Feasibility Study, and particularly the development of the Design Guideline. Any missing parameters will be identified and addressed by utilizing design guidelines from recent Canadian LRT and streetcar projects, including the region's first modern LRT system, the Surrey-Newton-Guildford LRT. Additionally, the lessons learned from Arbutus Greenway Additional Streetcar scope regarding steep gradients on Arbutus Street between 3rd – 37th Avenue will be incorporated. This will ensure the variety of existing conditions and operating environments of the future streetcar network are considered throughout the Feasibility Study.

Additionally, over the past 10 – 15 years the city has continued to grow and develop, meaning the current population and employment densities and future forecasts have changed. With this and the new planned and committed transportation improvements and updated stakeholder interests, it is necessary to update the ridership forecasts. This will be in parallel to streetcar technical considerations, confirmation of routing, capital and operating estimates, and concept development.

Appendix

Table 1: Future Streetcar Design Criteria from NEFC – Streetcar Implementation Considerations Memo (WSP | MMM, 2017)

Table 1: Future Streetcar Design Criteria

Future Streetcar Design Criteria				
Item	**Proposed Criteria**	**Opening Day Design**	**Comments**	**Review of TCRP Report 155 for LRT**
Design Vehicle Width	2.65m	N/A	Upper limit of the typical range of streetcar widths.	12.2.1 Streetcar width is usually approx. 0.61m less than lane width.
Lane Width	3.4-3.5m	3.4 - 3.5m	Future streetcar shall be accommodated mostly in the curb lanes with a future curb lane width of 3.5m, attained by slight reductions in adjacent thru lanes (either to 3.0 or 3.05m). Additional widening of lanes around curves shall be dictated by turning envelope of design vehicle.	12.2 Typical urban lane widths are between 3.0m and 3.3m.
			3.5m lane width generally accommodates larger design vehicle.	12.2.1 Streetcar dynamic envelope must not encroach into adjacent travel lanes.
Radius	Min. 18 – 25m	30m (SW corner of Quebec/Pacific)	Reduced speed required with radii less than 150m. Upper range on minimums preserves for larger range of streetcar technologies	3.2.3.2 and 12.4.1 25m is the most common minimum for LRVs. The use of curves tighter than 25m is therefore strongly discouraged.
	Desirable 150m	100m (between Expo & Carrall)		3.2.3.3 A common acceptable minimum is 150m, which is a frequent threshold limit for the use of guard rails or grooved rails.
Vertical Profile Grades - Longitudinal	Max 5%	0.5% to 2% (west of Georgia Ramp)	Current profile does not exceed 2%. The 5% proposed criteria is an average of the two TCRP desired maximum grades and would not require the procurement of a vehicle with higher-than-average performance capabilities.	3.3.2.1 Recommendations include: 1. desired maximum 4%, unlimited length; 2. desired maximum 6%, for up to 750m in length; and 3. absolute maximum 9%, requiring confirmation with vehicle manufacturer.
Vertical Profile Grades - Stations	Max 2%		Max 2% at stations. For accessibility requirements, the Americans with Disabilities Act Accessibility Guidelines (ADAAG) is generally accepted industry-wide.	3.5.2 Stations should be located on tangent grades: Minimum Desired: 0.5% for drainage considerations, Absolute Maximum: 2.0% for accessibility requirements.
Crossfall	0-2%	Typically 2%	Tracks should ideally be at 0%, 1% max if curbside and drainage needs to be maintained. Zero cross slope at special track locations and platforms is good industry practice, the former for constructability and maintenance considerations, the latter to achieve level boarding in order to meet accessibility requirements.	12.7.2 Cross slope can be 2%, with 2.5% being the limit at which passenger comfort is sacrificed. 12.7.2.3 Special track areas require zero cross slope. No specific criteria is given for track cross slope at platforms.
Crossfall Transition Length	1:400	1:400	Considerations need to be made on transitions of superelevations / cross slope changes. For streetcars, the length is dictated by the amount of twist that can be accommodated by the vehicle.	2.4.5 Some agencies prescribe values as high as 2‰ (1:500) meaning 500 units of track length for every 1 unit of superelevation or cross level imbalance. A common industry threshold is 1:400.
Design Vehicle Length	35 m	N/A	A relatively common single streetcar length is 30m, which matches the latest Toronto streetcar vehicle (Bombardier, 30.2m), for example.	2.3.2.1 No specific range is given. Overall vehicle length includes not only body length, but also couplers, if equipped.
Platform Tangent Length	Min: 35m + (2 x 10m)	Propose bus stop landing area: 15m	10m long tangent segments needed on either side of platform. Most modern articulated streetcars are able to traverse 10m tangent lengths, or less, beyond platforms without violating accessibility requirements.	3.5.1 Minimum tangent lengths are noted as: Desired: 25m, Acceptable: 20m, Absolute: 15m. Several options are noted for where desired tangent can't be achieved, including limiting the usable platform edge, and placing track on a relatively flat curve (600m radius).
Platform Width	Min. 3.0m	Min. 3.0m	Future platform accommodation will require reconfiguration of sidewalk and cycle tracks. 3m is a common industry requirement for side platforms.	Not specified.
Platform Height	0.2m-0.35m (Low Floor Vehicle)	Typically 0.15m (standard curb)	The range of values allows for a larger spectrum of low floor vehicle technologies.	12.3 Station platforms shouldn't be extended into the roadway, tracks should be adjusted to match the curb to meet accessibility requirements.
Lane Shift Transition	TBC during streetcar design	N/A	Separate phases can be given to the streetcar to make transitions across the normal traffic movements.	3.2 Recommended horizontal alignment criteria for curve lengths and tangent lengths is provided. 12.2.1 Streetcar dynamic envelope must not encroach into adjacent travel lanes.
Drainage	TBC during streetcar design	Typically drains to curbside	N/A	4.7.4.4.1 Storm water will be captured in the flangeways and flow longitudinally along the rails rather than transversely into the gutters. Special provisions, such as track drains, will be needed to deal with this runoff.
Utilities	Refer to Streetcar Utilities Design Criteria memo		Many LRT systems do not permit any utilities within 4m of the nearest track centre line. Utilities which cross the tracks should be encased and situated at a depth of around 2m.	13.2.5 Identification of track and utility interferences, and the implementation of acceptable mitigation measures, is imperative to prevent damage to utility infrastructure.

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