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ALTERNATIVES ANALYSIS SUMMARY & UPDATE

Rail to UBC Rapid Transit Study

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Project Partners:
University of British Columbia
City of Vancouver

Submitted to:
TransLink
400 – 287 Nelson's Court
New Westminster, BC V3L 0E7

Prepared By:
McElhanney Consulting Services Ltd.
200 – 858 Beatty Street
Vancouver BC, V6B 1C1

Contact:
Basse Clement, PEng, MASc
Strategic Transportation Planning Division Manager

In Partnership With:
WSP Global Inc.
Mott MacDonald Group
Thurber Engineering Ltd.

January 18th, 2019

TransLink – Planning and Policy
400 – 287 Nelson's Court
New Westminster, BC V3L 0E7

Attention: Brian Soland, Senior Planner

RAIL TO UBC RAPID TRANSIT STUDY – ALTERNATIVES ANALYSIS SUMMARY & UPDATE

As requested, we have prepared a revised summary report for this stage of the Rail to UBC Rapid Transit Study with feedback from TransLink, UBC, City of Vancouver, and Ministry of Transportation and Infrastructure. In this report, we provide a review of background studies and reports that have been conducted to date including a review of contextual elements since the previous evaluation in 2012. We also provide a summary of land use and demographics within the study area as well as a review of best practices in rapid transit planning elsewhere and then a suggested simplified method for evaluation of rapid transit alternatives. We provide updated ridership forecasts and cost estimates for each of the three rapid transit alternatives. For this revised report, we have included Part 2 which expands on some of the outstanding questions that came up during Part 1 of this study. Drawing upon this context, Part 3 provides a summary of findings with an analysis of trade-offs amongst the three preferred technology and alignment alternatives: Modified LRT 1, Combo 1, and RRT.

We trust you will find this summary of our review meets the requirements as set out in the scope of work. Please contact us if you have any questions or require any clarification.

Sincerely,

MCELHANNEY CONSULTING SERVICES LTD.

DRAFT

Basse Clement, PEng, MASc
Strategic Transportation Planning Division Manager

DRAFT

Bernard Abelson, PEng, MEng, TOPS
Branch Manager, Project Engineer

cc: Adam Hyslop, Transportation Planner, The University of British Columbia, Campus + Community Planning

200-858 Beatty Street
Vancouver BC
Canada V6B 1C1

Tel 604 683 8521
Fax 855 407 3895
www.mcelhanney.com

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EXECUTIVE SUMMARY

Previous Studies of Rapid Transit

This report provides a summary review of rapid transit alternatives along the Broadway corridor for the segment between Arbutus and UBC that have previously been developed and evaluated as part of the UBC Line Rapid Transit Study's Phase 2 Evaluation[1]. The Phase 1 portion of this previous study had narrowed down close to 200 alternatives (technology and alignment) to a short list of seven that were analyzed during Phase 2. Findings from this analysis were summarized in the Phase 2 Evaluation Report and provided technical information regarding ridership, costs, user benefits, and impacts for seven alternatives ranging from Best Bus to surface running Light Rapid Transit (LRT) to fully grade separated Rail Rapid Transit (RRT / SkyTrain). The Phase 2 Evaluation Report was completed in August 2012 which provided information to TransLink and its partners to decide on a preferred technology and route alternative. At the conclusion of the previous study, three alternatives showed promise in meeting the needs of the corridor through 2041 and were advanced for consideration in a regional investment planning process:

- **Light Rail Transit (LRT) Alternative 1**: Surface or partially tunnelled LRT from Commercial Drive to UBC via Broadway, West 10th Avenue, and University Boulevard;
- **Combo Alternative 1**: Combination of RRT (SkyTrain) and LRT, with tunnelled RRT from VCC-Clark to Arbutus, and surface LRT operating from Main Street-Science World to UBC; and
- **Rail Rapid Transit (RRT) Alternative**: Mainly tunnelled route from VCC-Clark to UBC via Great Northern Way, Broadway, 10th Avenue, and University Boulevard.

Mayors' Council Decision

The Mayors' Council identified rapid transit to UBC as a regional priority to be delivered in phases. In June 2014, the Mayors' Council Vision drew upon the outcomes of this alternatives analysis to identify the preferred technology and alignment option for rapid transit investment within the first ten years of the Vision: the Broadway Subway Project (BSP). This left a few options for further consideration including LRT Alternative 1[2], the Combo Alternative 1 and the extension of SkyTrain, or Rail Rapid Transit. The plan also noted the need for stakeholders to work together to confirm the preferred technology and alignment option for rail-based rapid transit between Arbutus and UBC. The Rail to UBC Rapid Transit Study was initiated by TransLink, the City of Vancouver, and the University of British Columbia as a first step towards achieving this outcome.

Changes Impacting Analysis

This study has provided an update of contextual elements and key changes since 2012 that will impact some of the key metrics within the evaluation of alternatives. Some of the notable changes since 2012 include the following:

- Transit ridership has increased significantly with the opening of the Evergreen Extension of the Millennium Line, continued demographic and economic growth as well as high fuel prices;
- Housing affordability has eroded along with rental vacancy and cost of travel necessitating the need to intensify development of multi-family housing that is located within a reasonable walk distance of rapid transit stations;
- Each of the participating agencies have set ambitious sustainable mode share targets that require significant investment in transit service to be fully realized;

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[1] UBC Line Rapid Transit Study – Phase 2 Evaluation Report, Steer Davies Gleave/SNC Lavalin, August 2012.
[2] For a consistent evaluation of the alternatives, a modified LRT 1 scenario has been assumed to include the BSP extension to Arbutus and then surface-running LRT from Arbutus to UBC.

- There have been significant changes in land ownership and development potential along the study corridor including the Jericho Lands, Musqueam “Block F” development in the University Endowment Lands, and an updated UBC Campus Plan. Further campus planning scenarios are emerging that envision further development of educational and recreational facilities as well as student, market and non-market housing.
- Favourable economic conditions, a low Canadian dollar relative to the US dollar has resulted in construction cost escalation necessitating a review of previously develop construction costs.

Review of Best Practices in Rapid Transit Planning

A review of best practices in rapid transit planning across North America has suggested that a more simplified approach to planning and evaluation of rapid transit alternatives should be undertaken. In order to support a clear and definitive recommendation for rapid transit and inform a decision on technology, alignment and station locations, a filtering of alternatives should be conducted early on so that only feasible alternatives are further developed. Further, presenting only key accounts within a multiple account evaluation that relate directly to the project goals and objectives is suggested so that a technically feasible alternative is presented that is supportive of regional and local agencies and stakeholders.

Confirmation of Line Times, Headways and Capacity for LRT

A benchmarking exercise of line times, headways and capacity for surface-running light rail transit across systems in North America and Europe was undertaken to provide a realistic assessment for this technology alternative. Given the right-of-way constraints, density of intersections and capacity of the Broadway corridor, a realistic average operating speed of 25 km/h was determined which is significantly slower than the 29 km/h assumed in the Phase 2 Evaluation. A headway of four minutes would be achievable with the assumed operating plan for LRT along Broadway without significantly affecting service reliability. The peak directional capacity for LRT is approximately 7,200 passengers per hour per direction which is realistic given the frequency and vehicle types assumed. It is worth noting however that this volume is not observed in any of the benchmark systems as those LRT systems that carry this many people tend to be fully grade separated. A detailed operating model for surface running LRT was developed to confirm these parameters, particularly that an LRT would realistically operate at approximately 25 km/h along the study corridor.

Updated Regional Transportation Model

A significantly updated version of the regional transportation model has been developed and released since the Phase 2 Evaluation. The updated model includes a refined traffic zone system, updated land use, updated road and transit networks and an updated model formulation. One of the key differences with the new model is the introduction of the congested and capacity constrained transit assignment procedure which provides a more realistic estimate of ridership forecasts. Finally, updating enrollment projections for UBC in the model to reflect recent enrollment growth and increased housing capacity has resulted in higher ridership demand than previously estimated. For the purposes of developing ridership forecasts for this study, the B-Line, Modified LRT 1, Combo 1, and RRT transit options were modelled with the inclusion of the BSP which has been committed to in the Mayors’ Council 10-Year Vision. The Modified LRT 1 includes the BSP to Arbutus and then surface-running light rail transit from Arbutus to UBC.

Updated Construction Cost Information

Updated construction cost information for the Broadway Subway Project and the Surrey Light Rail Transit project have been recently released. This information, along with updated cost information from the Evergreen Extension of the Millennium Line, have provided a basis for updating construction cost estimates for the Modified LRT 1, Combo 1, and RRT alternatives. These are presented in the final summary table, shown in *Table E-1*. Favourable economic conditions and a low Canadian dollar has resulted in construction cost escalation which is reflected in these updated cost estimates with an assumed contingency of 40-60%.

Additional Review and Analysis

The review and analysis are presented in two parts. The first part provided further information that support the evaluation of rapid transit alternatives for the study corridor since the 2012 Phase 2 Evaluation was completed. Several additional questions were raised at the conclusion of Part 1 and these are addressed in Part 2. They include the following:

- **Review of Additional LRT Scenarios:** Capacity was one of the biggest concerns for the LRT scenarios in terms of meeting long term ridership and mode share objectives. As such, extensions of each LRT scenario from UBC along 41st Ave to Metrotown were further developed and evaluated to explore the total cost and ridership implications of delivering more than one rapid transit corridor. In terms of ridership, generally two LRT corridors are equivalent to one RRT corridor, though the capacity of the two LRT lines serving UBC is approximately half of the max build-out capacity of the RRT alternative.

- **Review of Alternate UBC Enrollment Scenario:** Questions were raised about UBC's Campus Plan and their ability to achieve enrollment forecasts in the long term. A lowered UBC enrollment scenario was carried out to determine if LRT or RRT would meet capacity requirements.

- **UBC Station Capacity Review:** Over 10,000 passenger boardings and alightings are forecast for the UBC station for the 2045 AM peak hour. This is higher than the busiest SkyTrain station currently and necessitated a review for feasibility. With good design principles, this level of activity can be supported with one station.

- **Opportunities for Best Bus Service:** A review of best bus service was reviewed in terms of capacity and run time. The highest likely capacity is 3,600 pphpd and an operating speed of 25-28 km/h.

- **Development of Partially Elevated SkyTrain:** A conceptual design and cost estimating review was carried out for a partially elevated SkyTrain alignment west of Blanca St. This was reviewed to look at potential construction cost savings for the RRT scenario. West of Blanca, an elevated SkyTrain guideway would cost approximately 36% less than a tunnelled corridor. Note that the partially elevated SkyTrain alignment was considered for the segment west of Blanca for planning purposes only due to construction feasibility of the tunnel portal and lower property and business impacts. Further analysis would be undertaken to identify which portions of the RRT would be elevated should the RRT option advance to a business case.

Evaluation of Alternatives

Based on the evaluation of the three alternatives (Modified LRT 1, Combo 1, and RRT) against the base case scenario (B-Line + BSP), all three rapid transit options increase transit trips but both LRT based options are close to or exceeding practical capacity within the 15-year time horizon of this study. The RRT option increases transit trips and mode share to and from UBC the most as it provides a transfer-free service with the fastest and most reliable operating speed. Furthermore, SkyTrain is the only technology that has the capacity to meet projected travel demand in the corridor and provides a system that is future-proof for over 50 years. All other alternatives fall short of these requirements. A summary of key accounts is presented in *Table E-1* which shows that RRT scores highest in most evaluation accounts which are related directly to the project objectives.

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Table E-1: Summary of Rapid Transit Technology Alternative Evaluation

	B-LINE + BSP	MODIFIED LRT 1	COMBO 1	RRT
	B-Line from Arbutus to UBC	LRT from Arbutus to UBC	LRT from Main Street-Science World to UBC / LRT from Arbutus to UBC	RRT from Arbutus to UBC
TRACK LENGTH	–	7.1 km	12.0 km	7.1 km
NUMBER OF STOPS	–	5	10	4
TRANSFERS Expo Line to UBC Millennium Line to UBC	 2 1	 2 1	 1 1	 1 0
TRANSIT TRAVEL TIME In-Vehicle Time (mins) End-to-End Time Including Walk Access and Wait Times (mins)	 20 22	 17 19	 28 / 17 30 / 19	 10 11
RELIABILITY* On time performance (%)	55-67%	83-89%	83-89%	95-97%
CAPACITY Practical Capacity Theoretical Capacity Max Build-Out / Expansion Capacity	 2,100 2,400 2,400	 6,120 7,200 7,200	 6,120 7,200 7,200	 10,660 12,500 26,000
PEAK DIRECTIONAL LOAD (2045) Peak Load % of Practical Capacity	 2,600 124%	 5,900 96%	 6,600 108%	 10,000 94%
DAILY BOARDINGS (2045) On Arbutus-UBC Segment	28,800	66,100	135,300 / 100,500	118,800
NEW DAILY TRANSIT RIDERS/TRIPS (2045) Systemwide	–	4,000	16,000	13,600
AUTO TRAVEL TIME (2045) Time (mm:ss) from Commercial Dr–UBC (% difference relative to B-Line scenario)	36:30	37:30 (+3%)	36:25 (0%)	35:10 (-4%)
TOTAL REGIONAL VKT DURING AM AND PM PEAK PERIODS Total VKT (2045)	10.92 M km	10.93 M km	10.91 M km	10.89 M km
PRELIMINARY ESTIMATED COST (2018 $)*** Based on EGL and BSP unit costs Includes 40-60% contingency	–	$1.7B to $2.0B	$2.8B to $3.2B	$3.3B to $3.8B $3.1B to $3.5B**
DELIVERABILITY CHALLENGES	▪ Minimal	▪ At-Grade Alignment ▪ Business and property impacts ▪ OMC Requirements	▪ At-Grade Alignment ▪ Business and property impacts ▪ OMC Requirements	▪ Bored Tunnelling ▪ Business and property impacts at stations

** B-Line reliability is based on TSPR revenue hours not overcrowded.*
*** Cost for partially elevated SkyTrain west of Blanca*
**** Costs at the actual time of construction would be impacted by inflation between 2018 and construction period.*

PART 1: INITIAL REVIEW

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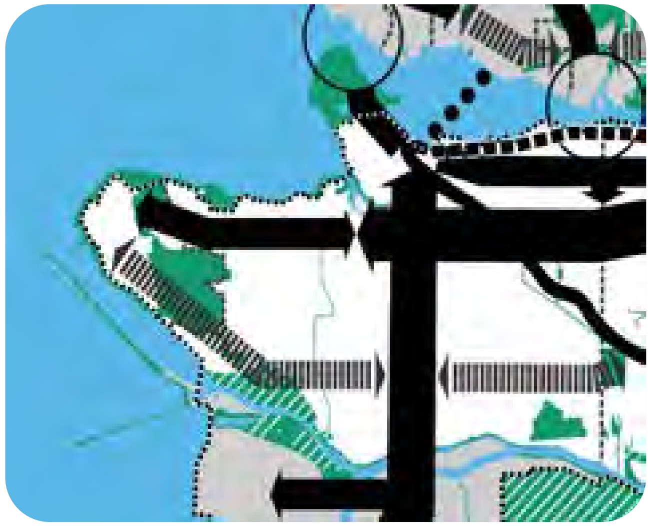
1. INTRODUCTION & PROJECT BACKGROUND

The need for a rapid transit connection between central Broadway and UBC was identified in the 1990s in the Greater Vancouver Regional District's (GVRD) Livable Region Strategic Plan (*Figure 1-1*). First introduced in 1996, the 99 B-Line bus service quickly became a popular express route and is now the busiest bus route in Canada and the US, with average weekday ridership of over 55,000 passengers. A new high-capacity rapid transit connection would build upon the ridership of the existing corridor bus services (which operate above capacity during peak periods) and would alleviate the 99 B-Line's current travel time and reliability issues.

Figure 1-1: GVRD's Livable Region Strategic Plan – Regional Transit System



Both UBC and the Broadway corridor are recognized as key regional destinations. Each is a significant generator of commuter (work and educational), shopping, and recreational trips. These areas, including outlying areas connected by the Millennium and Expo SkyTrain lines, are expected to further densify as the region continues to grow and demand for housing and employment continues to increase. Providing a higher-order rapid transit service will allow TransLink, the City of Vancouver, UBC, and the Metro Vancouver region to achieve their ambitious sustainable mode share targets and support anticipated development.

The extension of rapid transit from the current planned terminus at Arbutus (Broadway Subway Project – BSP) needs to achieve the broad range of capacity, regional connectivity, reliability and sustainable mode share objectives articulated by the partner agencies. It also needs to be delivered in a manner sensitive to the very different urban environments through which it travels – from the edge of the Metro core, to local-serving regional arterial, to residential, greenspace, and campus environments. These present a range of transportation and urban development challenges and opportunities unique to individual line segments, including retaining local character, scale and development conditions, large parcel opportunities, First Nations interests, and support for UBC's Campus Plan.

1.1 REGIONAL & BROADWAY / 10TH AVENUE PERSPECTIVE

The Broadway / 10th Ave corridor as shown in *Figure 1-2,* is encompassed by Arbutus St to the east, 4th Ave / Chancellor Blvd to the north, 16th Ave to the south and the UBC campus to the west. There are numerous activity centres along this corridor generating a significant amount of travel demand that are connected by local streets and transit services. The density and mixture of land use types is also supportive of transit usage as well as walking and cycling. The general streetscape is also well served with sidewalks on both sides of most streets including recent enhancements to the Seaside Greenway connected to a comprehensive cycling network including the Arbutus Greenway.

Figure 1-2: Rail to UBC Rapid Transit Study Boundary

Note: Focus of analysis in this study has been within this boundary, however the Combo 1 alternative extends east to the Main St/Science World Station.

Ranging from a campus / institutional setting in the west, through greenspace to more residential and commercial lands in the east, the UBC to Arbutus study area exhibits unique characteristics which distinguish it from the rest of the region. For the purposes of facilitating land use analysis, the study area has been divided into three smaller geographic regions: University of British Columbia (UBC), University Endowment Lands (UEL), and Blanca Street to Arbutus Street. These were defined based on considerations of their respective land use patterns, built form, and jurisdictional boundaries.

1.1.1 UBC Campus

The westernmost portion of the study area is home to UBC. UBC is a global centre for research and teaching that is now ranked as one of the top 20 public universities in the world. With 56,000 students and 15,000 faculty and staff, UBC is the region's third-largest employment centre after downtown Vancouver and Central Broadway. With visitors and non-UBC workers, the campus daytime population is estimated to be over 75,000 people. Land uses within this district are predominantly institutional with pockets of residential, commercial and recreational land uses, as seen in *Figure 1-5*. UBC Hospital along with UBC's primary teaching, research, and sports facilities are all concentrated within the northern half of UBC's campus lands, centred around University Boulevard and Main Mall. In addition, a variety of research, institutional, and teaching facilities are located at the south end of the campus. Immediately to the west of Lower Mall are residential complexes which support student housing for graduate and undergraduate students, as well as general housing. Over 12,000 students living in residence and over 11,000 neighbourhood residents call UBC home. These numbers are expected to grow over the coming decade as UBC continues to build out planned neighbourhoods and construct additional student residences. Land uses adjacent to Wesbrook Mall to the east and throughout the Wesbrook Village feature a variety of complementary land uses including mixed-use developments and commercial and institutional uses. The remaining areas are characterized by pockets of undeveloped land, open spaces, or protected natural areas.

1.1.2 UEL

The University Endowment Lands (UEL) border the UBC district to the north and to the east. Aside from the single-family neighbourhood that occupies the area to the north of University Boulevard, the existing land is primarily reserved for either recreation purposes, open spaces, or protected natural areas. Block F, a 21-acre site within the UEL (*Figure 1-3*), located south of the proposed rapid transit corridor, is currently under development. The Province of British Columbia transferred the land to the Musqueam First Nation in 2008 as part of a Reconciliation, Settlement and Benefits Agreement. When built out, Block F will include 1.2 million sq. ft. of multi-family residential development and 30,000 sq. ft. of commercial development. The 59-hectare UBC Golf Club lands were also transferred to the Musqueam under this agreement, though with the requirement that a golf course be kept in place until 2083. It is reasonable to assume that considerable additional development could take place on these lands after that time.

Figure 1-3: Block F Located Within UEL

1.1.3 10th Avenue / Broadway Corridor

Moving eastward towards Arbutus, current land uses along 10th Avenue and Broadway are mainly characterized by single-family homes and low rise mixed-used buildings, interspersed with commercial properties within close proximity of the corridor (*Figure 1-5*). Residential areas are characterized by older homes, many of which have heritage value and are not anticipated for significant redevelopment or densification. Once at Arbutus, there is a greater mixture and density of commercial and residential properties with ground-level retail. The densities continue to rise further east towards Central Broadway.

Figure 1-4: Jericho Lands in West Point Grey

Situated in the West Point Grey neighbourhood, the Jericho Lands is a 36-hectare property bounded by West 4th Avenue to the north, Highbury Street to the east, West 8th Avenue to the south and Discovery Street to the west (*Figure 1-4*). The Jericho Lands are comprised of two portions: Jericho Garrison and Jericho Hill. The Jericho Garrison is a 21-hectare site on the eastern portion of the Jericho Lands that was formerly owned by the Department of National Defense. In October 2014, this property was acquired by the Canada Lands Company and the Musqueam, Squamish and Tsleil-Waututh (“MST”) Nations in a joint venture. The MST Partnership also acquired the adjacent western property, known as the Jericho Hill, from the Government of BC in 2016. This western portion is roughly 15 hectares in size with parts of the property leased to the Vancouver Park Board and the West Point Grey Academy. With the approval of the Jericho Lands Policy Planning Program, the Jericho Lands is currently being planned for redevelopment that will likely see higher densities and mixed use than is currently there today.

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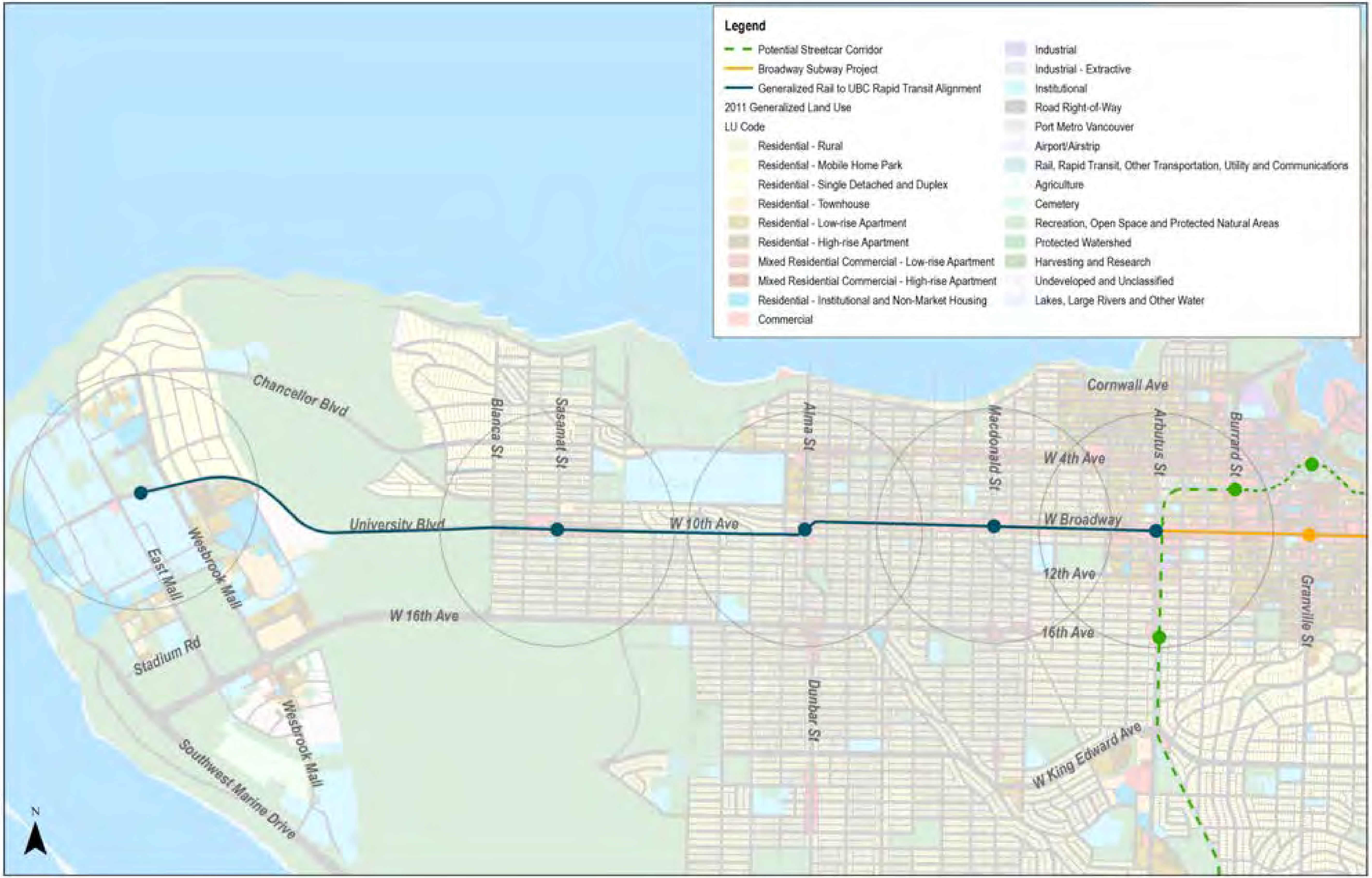
Figure 1-5: Metro Vancouver's 2011 Generalized Land Use Map



1.1.4 Existing Transit Services

The study area is currently well served by east / west bus routes as well as north / south services that connect key areas of Vancouver and UBC as shown in *Figure 1-6*. The Broadway / 10th Ave corridor is served by the 99 B-Line which is a limited stop, high frequency transit line serviced with articulated buses running in curb-side bus only lanes during peak periods along a portion of the route. Bus lanes are converted back to parking lanes during the midday and off-peak periods when buses are required to share a general-purpose lane in mixed traffic. Note that the peak period bus lanes end at Arbutus St. The 4th Ave, 16th Ave, and 41st Ave corridors are also served with high frequency east / west bus services providing alternatives to the 99 B-Line as summarized in *Table 1-1,* showing estimated corridor operational capacities. The operational capacity for each corridor ranges from 900 to 2,500 passengers per hour per direction (pphpd) resulting in a collective UBC screenline capacity of approximately 6,950 pphpd.

The Broadway corridor is essentially at capacity in terms of bus-based service levels and requires investment in rapid transit in order to provide more reliable service. Although there are several route choices on alternate corridors and high frequencies, this area still suffers from overcrowding, delays and reliability issues. All buses operate in mixed traffic[3] with limited priority at signalized intersections. The Canada Line, Expo Line, Millennium Line, and a variety of north / south bus routes connect with feeder routes to the 99 B-Line. This network provides a supportive framework for the introduction of a rapid transit service along the corridor.

Figure 1-6: Current Transit Network within the Study Area

Source: TransLink website < http: / / infomaps.translink.ca / System_Maps / 136 / V-Sep%202017.pdf>.

[3] *Mixed with right-turning vehicles, bicycles, emergency vehicles, etc.*

Table 1-1: Summary of Existing East / West Bus Services in the Study Area

Corridor	Bus Route	Headway (mins)	Bus Route(s) Operational Capacity (passengers per hour per direction)	AM Westbound Peak Hour Ridership
4th Ave / Chancellor Blvd	44	8	565	580
	84	6	500	360
	Total	-	1,065	940
Broadway / 10th Ave / University Blvd	4	15	220	130
	9	10	330	250
	14	10	330	250
	99	3	1,500	1,680
	258	30	100	100
	Total	-	2,480	2,410
16th Ave	25	5	600	630
	33	10	300	380
	Total	-	900	1,010
41st Ave / SW Marine Dr	41	5	600	640
	43	6	750	610
	49	6	750	570
	480	7.5	400	590
	Total	-	2,500	2,410

Sources:

Operational Capacity -TransLink's 2016 Transit Service Performance Review, Appendix B: Report Definitions and Assumptions, p.5
Headways – TransLink's Transit Schedules

1.2 PREVIOUS STUDIES

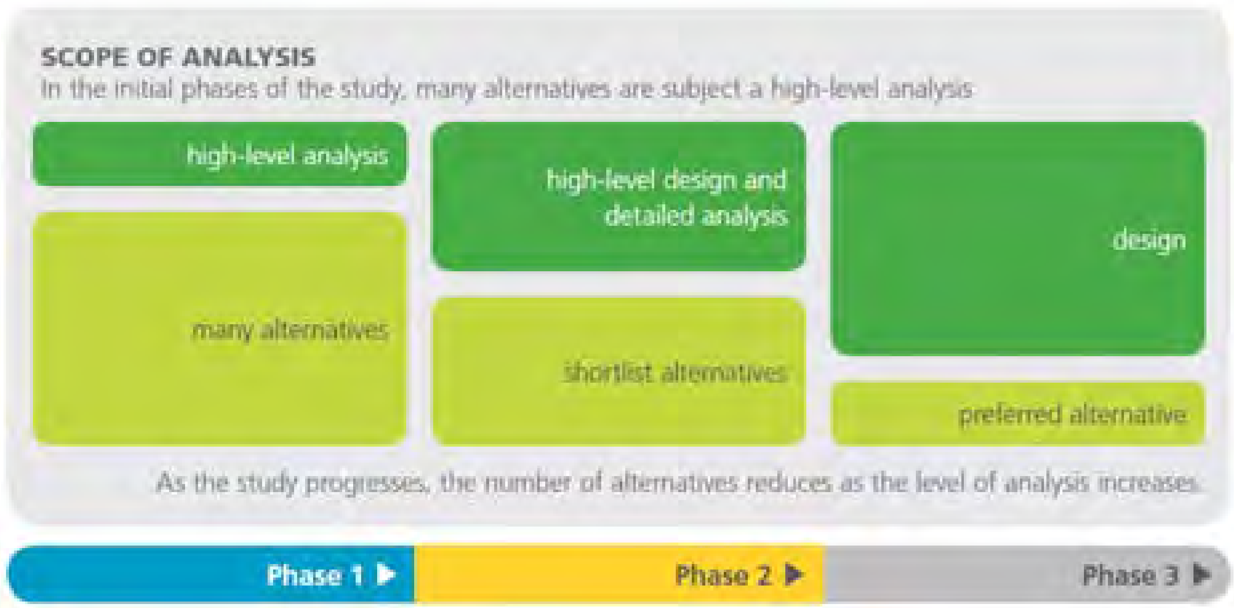
From 2009-2012, the UBC Line Rapid Transit Study, led by TransLink and the Province, with the City of Vancouver and UBC as partners, examined a wide range of rapid transit technology and alignment alternatives to serve the broader study area (see *Figure 1-7*), which extended from UBC to Broadway and Commercial, where the Expo and Millennium SkyTrain Lines intersect.

A multi-phased approach was employed (summarized in *Figure 1-8)* whereby a wide range of alternatives was reviewed and evaluated. As the study progressed through the phases, the number of alternatives was reduced while the level of analysis increased.

Figure 1-7: UBC Line Study Area

Source: TransLink website.

Figure 1-8: Multi-Phased Approach for the UBC Line Rapid Transit Study



Source: TransLink website.

In Phase 1 of the UBC Line Rapid Transit study, a Multiple Account Evaluation (MAE) framework was developed to screen a long list of over 200 possible technology and alignment options within the study area, and then evaluate the resulting shortlist of alternatives in more detail. This study recommended six alternatives to carry forward with a seventh being added due to public feedback.

The following objectives (organized by evaluation account) were developed early in the study:

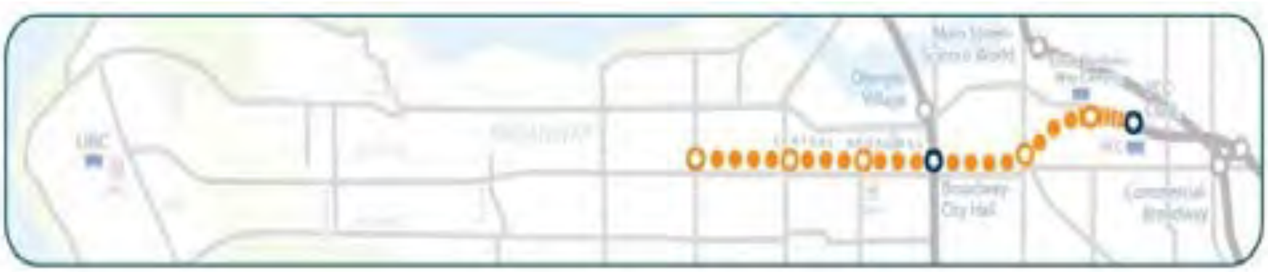
- **Economic Development:** A service that encourages economic development by improving access to existing and future major regional destinations and local businesses by transit while continuing to facilitate goods movement.
- **Environment:** A service that contributes to meeting wider environmental sustainability targets and objectives by attracting new riders, supporting changes to land use and reducing vehicle kilometres travelled (VKT).
- **Financial:** An affordable and cost-effective service.
- **Social and Community:** A safe, secure and accessible service that also improves access to rapid transit for all and brings positive benefit to the surrounding communities, including managing impacts of rapid transit.
- **Transportation:** A fast, reliable and efficient service that meets current and future capacity needs, supports achieving transportation targets and integrates with and strengthens the regional transit network and other modes.
- **Urban Development:** A service that supports current and future land use development along the Corridor and at UBC and integrates with the surrounding neighbourhoods through high quality urban design.
- **Deliverability:** A service that is constructible and operable.

At the conclusion of the study, three alternatives showed promise in meeting the needs of the corridor through 2041 and were advanced for consideration in a regional investment planning process:

- **Light Rail Transit (LRT) Alternative 1:** Surface or partially tunnelled LRT from Commercial Drive to UBC via Broadway, West 10th Avenue, and University Boulevard;
- **Combo Alternative 1:** Combination of RRT (SkyTrain) and LRT, with tunnelled RRT from VCC-Clark to Arbutus, and surface LRT operating from Main Street-Science World to UBC; and
- **Rail Rapid Transit (RRT) Alternative:** Mainly tunnelled route from VCC-Clark to UBC via Great Northern Way, Broadway, 10th Avenue, and University Boulevard.

In June 2014, the Metro Vancouver's Mayors' Council Vision drew upon the outcomes of this alternatives analysis and identified the Broadway Subway Project (BSP) (*Figure 1-9*) as the preferred technology and alignment option for rapid transit investment within the first ten years of the Vision.

Figure 1-9: Broadway Subway Project (BSP)



The Vision also committed all stakeholders to "work together to conclude how and when to complete the next phase of rail to the Point Grey campus" during the design process for the first phase, now underway. Rapid transit to UBC could be introduced through: (a) a further extension of the Millennium Line to complete the RRT Alternative, (b) the introduction of a new LRT line from Main Street-Science World to UBC to complete Combo Alternative 1 or (c) introduction of other rapid transit options linking the Arbutus terminus of the BSP with UBC.

With approved funding for TransLink's Phase One Investment Plan, technical and public engagement work is advancing to develop a final reference case design and associated procurement documents for the BSP. Questions regarding the connection of rapid transit to UBC have featured prominently in early stakeholder and public engagement discussions. Many stakeholders have highlighted potential efficiencies associated with delivering rapid transit on the full corridor as a single project or through uninterrupted phased construction.

The Province, TransLink, and the City continue to advance the design and construction of the Millennium Line SkyTrain extension to Arbutus. In support of these developments, the need was identified to summarize and update the findings of the 2009-2012 alternatives analysis process in light of current realities, and establish a high-level project scope definition, technology preference and cost estimate for the next phase of rapid transit to UBC.

1.3 CURRENT STUDY PURPOSE

Since the Phase 2 Evaluation was concluded in August 2012, changes to the socio-economic, development, land use planning, and funding landscapes have brought this project into closer focus, necessitating a review to validate the assumptions and conclusions of previous studies. Further, confirmation of capacity requirements to meet regional and local sustainable mode share targets is required to ensure the system is scalable for long-term needs.

An independent review and validation of previous planning and technical work was therefore commissioned to support the identification / confirmation of a preferred technology. This will bolster confidence in the planning work already undertaken and ensure that recent changes (in land use for example) are accounted for. Further, a significantly updated Regional Transportation Model has been released since the previous study took place which has provided more confidence in ridership forecasts. Subsequent work will be needed to develop a high-level project definition and cost estimate for business casing purposes, as well as to support funding discussions with various levels of government.

1.3.1 Study Approach

The purpose of this report is to review the methodology, process, ridership forecasts and outcomes from the previous work completed in 2012, and to confirm that the conclusions remain valid, while setting the stage for more detailed project definition work to refine the alignment and station locations, based on the conclusions from the review.

The methodology encompasses a review of the evaluation and reports prepared as part of the previous Phase 2 study in 2012, summarizing and updating components of the alternatives analysis; an assessment of changes to the planning context since completion of the previous study and the implications of these changes; a best practice review of rapid transit planning projects and a benchmarking assessment of global transit systems to validate the inputs into the Phase 2 ridership forecasts and business case; a review and update of the Phase 2 costs; and a proposed framework for assessing and evaluating alignment and station location options.

1.4 REPORT OUTLINE

This report is presented in three parts following this introduction as outlined below:

Part 1 – Initial Review

Section 2: Review of Project Definition and Business Case Materials: Discusses previous background reports and studies as well as the multiple account evaluation.

Section 3: Contextual Elements: Provides a review of what has changed in the political, socio-economic and demographic context since the completion of the Phase 2 evaluation five years ago.

Section 4: Rapid Transit Planning Best Practices: Provides a review of rapid transit planning best practices including multiple account evaluation drawing on experience from other parts of Canada and the US.

Section 5: Benchmarking Surface Running LRT: Provides a review of the operational characteristics assumed for the LRT alternatives during the Phase 2 Evaluation and an overview of LRT rapid transit systems across Canada and internationally.

Section 6: Review Deliverability of LRT Speed and Capacity: An operational model was developed to determine the highest likely speed and capacity for light rail transit along the Broadway/10th Ave corridor.

Section 7: LRT Property and OMC Requirements: A review of property and OMC requirements was carried out to determine the magnitude of property required and footprint for a maintenance facility.

Section 8: Review of Ridership and Costs: Discusses the approach and methodology followed to produce updated ridership and cost estimates.

Section 9: Mode Share Targets: Discusses the trade-offs between the rapid transit alternatives with regards to transit mode share targets, capacity, and costs.

There were outstanding technical questions that were noted at the conclusion of Part 1 of this study necessitating Part 2, which provided further technical analysis to further support the conclusions previously determined. The following provides the outline for Part 2 of this study:

Part 2 – Additional Review and Analysis

Section 10: Review of Additional LRT Scenarios: Summarizes additional LRT scenarios that were modelled to provide sufficient capacity to meet ridership demand to UBC. This included an extension of the LRT 1 and Combo 1 alternatives along 41st Ave to Oakridge and Metrotown.

Section 11: Review of Alternate UBC Enrollment Scenario: A sensitivity scenario was carried out to determine the impact of lowered enrollment forecasts for UBC. This information was used to determine if sufficient capacity is provided by all technology alternatives.

Section 12: UBC Station Capacity Review: Almost 10,000 passengers in the morning peak hour are forecast to alight at the UBC station in 2045. A review of station requirements was carried out to determine if moving this level of passenger activity is feasible at the UBC station.

Section 13: Opportunities for Best Bus Service: With the anticipated completion of the Broadway Subway Project in 2025, a review of the existing 99 B-Line to service passengers to UBC was carried out. This included reviewing highest likely capacity with bus-based service.

Section 14: Development of Partially Elevated SkyTrain: In order to minimize costs of SkyTrain technology, a partially elevated SkyTrain alignment west of Blanca St was developed along with updated construction cost estimates.

Part 3 – Summary of Findings

Section 15: Summary of Findings: An updated evaluation of alternatives including trade-offs between rapid transit technology alternatives is presented.

2. REVIEW OF PROJECT DEFINITION & BUSINESS CASE MATERIALS

The 2012 Phase 2 Evaluation which formed part of the UBC Line Rapid Transit Study was completed in August 2012. This section provides a summary of the previous planning and evaluation work undertaken to determine preferred alternatives for extending rapid transit from Broadway / Commercial to UBC. These will be revisited in the Rail to UBC Rapid Transit Study.

2.1 SUMMARY OF PREVIOUS PLANNING & MAE

The Phase 2 Report provided a high-level evaluation of seven rapid transit alternatives ranging from a best bus (BB) alternative to rail rapid transit (SkyTrain) and variations in between, including Light Rapid Transit (LRT). The following provides a summary of the previous problem statement, project vision, mission and objectives.

2.1.1 Problem Statement

The technology and alignment alternatives were developed in response to the following problem statements:

- Existing transit services do not provide sufficient **capacity** or **reliable** enough service to the major regional destinations and economic hubs within the Broadway corridor;
- **Transit trips** and **mode share** need to increase to **reduce vehicle kilometres travelled** (VKT) and **GHG and CAC emissions**, both directly and by supporting the Regional Growth Strategy and other regional objectives; and
- Regional funding for transit is limited and needs **to balance a range of rapid transit investment priorities**.

While not stated in the report, all public documents referred to capacity, speed and reliability as primary criteria for rapid transit along this corridor.

2.1.2 Project Vision

A rapid transit service that serves and shapes a great region and communities and strengthens its livability and sustainability by providing a viable alternative to the private car.

2.1.3 Project Mission

To plan a rapid transit service that is accessible, convenient, safe, reliable and environmentally and financially sustainable that integrates with the regional transportation system and contributes to the achievement of transportation, environmental and land use objectives and targets.

2.1.4 Project Objectives

- **A fast, reliable and efficient** service that **meets current and future capacity needs**, supports achieving transportation **targets** and **integrates** with and strengthens the regional transit network and other modes;
- An **affordable** and **cost-effective** service;
- A service that contributes to meeting wider **environmental sustainability** targets and objectives by attracting **new riders**, supporting changes to **land use** and **reducing vehicle kilometres travelled**;

- A service that supports current and future **land use development** along the Corridor and at UBC and integrates with the surrounding neighbourhoods through **high quality urban design**;
- A service that encourages **economic development** by improving access to existing and future major regional destinations and local businesses by transit while continuing to facilitate goods movement;
- A **safe, secure and accessible** service that also improves access to rapid transit for all and brings positive benefit to the surrounding communities, including managing impacts of rapid transit; and
- A service that is **constructible and operable**.

The problem statement, vision, mission, and objectives all remain valid and will continue to serve as a guide in further developing and evaluating technology, alignment and station alternatives for rapid transit between Arbutus to UBC. In light of significant funding being required to upgrade existing systems such as the Expo and Canada lines, expandability and future proofing have become more relevant with rapid growth in transit ridership across the region. In addition, other rapid transit projects will be reviewed and best practices in evaluating transit alternatives will be developed. These are discussed in *Section 4*.

2.2 REVIEW OF PHASE 2 EVALUATION

In an effort to support improved understanding of the Phase 2 evaluation outputs, the Harvey Ball scoring system for the primary accounts and sub accounts is summarized in *Table 2-1.* As shown, each account is scored relative to the business as usual account. Note that the primary account score is a summary score which was developed by considering the scores within the sub accounts.

Table 2-1: Phase 2 Evaluation Scoring System

Phase 2 Evaluation Report Score	Worse	←	BAU	→	Better

The combined results for the primary and secondary accounts are shown in *Table 2-2* and indicate that overall and on an unweighted basis, RRT scores highest or among the highest of all the options and against all the accounts.

Note that no weighting of the individual accounts or sub accounts was applied in the Phase 2 report, and correspondence between the accounts, sub-accounts and the project objectives were not defined. As a consequence, biodiversity impacts are considered on par with impacts to transit users (which included travel time savings) and capacity. By weighting or prioritizing accounts in alignment with project objectives, alternatives which do not meet the minimum threshold can be screened out early and help to simplify and clarify the evaluation.

Table 2-2: Phase 2 Evaluation Account and Sub Account Scores

Criteria	Alternative						
	BB	BRT	LRT 1	LRT 2	RRT	Combo 1	Combo 2
Transportation	◑	◔	◕	◕	●	●	◕
Transit Users	◑	◑	◕	◕	●	●	●
Non-Transit Users	◑	○	○	○	●	◔	◔
Transit Network/System Access	◑	◑	◕	◕	◔	◑	◑
Reliability	◑	◑	◕	◕	●	●	◕
Capacity & Expandability	◑	◔	◕	◕	●	◕	◑
Financial	◔	◑	◑	◔	◑	◑	◑
Capital Cost	◑	◑	◔	◔	○	○	○
Operating Cost	◔	◑	◑	◑	◑	◑	◔
Cost Effectiveness	◑	◕	◕	◑	●	●	●
Environment	◑	◑	◕	◕	●	◕	◕
Appraisal Period GHG Emission Reductions (kilo-tonnes)	-17	128	235	203	335	309	238
Emission Reduction **Assumed score**	◑	◕	◕	◕	●	●	●
Noise and Vibration	◑	◑	◕	◕	●	◕	◑
Biodiversity	◑	◑	◑	◑	◑	◑	◑
Water Environment	◑	◑	◑	◑	◑	◑	◑
Parks & Open Space	◑	◑	◑	◔	◑	◔	◑
Urban Development	◑	◕	◕	◕	◕	◕	◕
Land Use Integration	◑	◕	◕	◕	●	●	●
Land Use Potential	◑	◕	◕	●	◕	●	◕
Property Requirements	◑	◔	◔	◔	◔	◔	◔
Urban Design Potential	◑	◕	◕	◕	◑	◕	◕
Economic Development	◑	◑	◕	◕	●	◕	◕
Construction Effects	◑	◑	◕	◕	●	●	◕
Tax Effects	◑	◑	◕	◕	●	●	●
Goods Movement	◑	◔	◔	◔	◕	◑	◔
Social Community	◑	◕	◕	◕	●	◕	◕
Health Effects	◑	◕	◕	◕	●	●	●
Low Income Population Served	◑	◕	◕	●	◕	●	●
Safety	◑	◕	◕	◕	●	◕	◕
Community Cohesion	◑	◔	◔	◔	◑	◔	◔
Heritage & Archaeology	◑	◑	◑	◑	◑	◑	◑
Deliverability (affordability not considered)	◑	◑	◑	◑	◑	◑	◔
Constructability	◑	◑	◔	◔	◔	◔	○
Acceptability	◔	◔	◕	◕	●	◕	◔

*Note: **Although no score was provided for emissions reductions, an assumed score has been estimated based on relative emissions reductions from the Best Bus (BB) scenario.*

The Phase 2 Evaluation report did not attempt to sum up scoring results, rather the information was presented as is with no weighting of accounts or filtering of alternatives. The report provides the scoring for each account, leaving it to the reader to determine their relative importance and interpret the results accordingly. One of the final comments in the 2012 report is “The results of the Phase 2 evaluation will help to inform the selection of a preferred alternative”. However, the report does not provide a definitive conclusion or recommendation as to a preferred option. Key observations with the Phase 2 Evaluation are noted below:

- Some consideration of filtering and weighting would help to determine if alternatives meet minimum thresholds and achieve the stated objectives as set out in the Phase 2 evaluation. For example, BRT arguably does not meet capacity requirements and performs poorly against economic development objectives.
- The Phase 2 evaluation determined that RRT provides benefits over other options to transit and non-transit users; capacity and expandability; noise and vibration; safety and acceptability.

Further commentary on the use of MAE and specific criteria to evaluate rapid transit alternatives within an urban context are provided in the sections which follow.

2.3 BEST PRACTICES IN RAPID TRANSIT PLANNING EVALUATION

This section describes key findings based on a review of the MAE criteria used in the Phase 2 Evaluation and other case studies. *Table 2-3* provides a comparison of the Phase 2 MAE accounts and other comparator rapid transit lines in North America. Many of the primary accounts are similar with a few exceptions such as Urban Development and Deliverability which were not used in a few of the comparator rapid transit lines.

Table 2-3: Comparison of MAE Primary Accounts used for Rapid Transit Lines in North America

BSP Phase 2	Toronto Crosstown	Waterloo ION	Ottawa Confederation Line	Los Angeles Purple Line Ext.	Maryland Purple Line
Economic Dev.	Economic Dev.	Land Use Economic Dev.	Economic / Financial	*	*
Financial	Financial	Financial	N/A	Cost Effectiveness	Cost Effectiveness
Environment	Environmental	Environmental	Environmental	Environmental Considerations	Environmental Benefits
Transportation	Transportation User Benefits	Transportation User Benefits	Public Transit	Mobility Improvement	Mobility Improvements
Social & Community	Social & Community	Social & Community	N/A	Public Acceptance & Equity	Operating Efficiencies
Urban Development	N/A	N/A	N/A	Transit-Supportive Land Use	Transit-Supportive Land Use
Deliverability	N/A	N/A	Strategic Fit	Project Feasibility	Other Factors

**Note: Financial / Financing and Economic Development assessments required outside of MAE.*

2.3.1 Number of Evaluation Criteria

The Phase 2 MAE lists 28 sub accounts used to evaluate the Broadway Subway Project. A best practice review of MAEs employed in other rapid transit studies, indicate that typically between 10-41 criteria are employed, with most project decision-making being based on 20-25 criteria. The risk of using a large number of criteria is twofold. First, with a large pool of criteria, no single criterion is meaningful in the overall evaluation with the result that it can be difficult to distinguish a clear leading option via the evaluation process as individual criterion carry limited weight. Further, where criteria are not weighted equally, the lesser-weighted criteria become effectively meaningless. Second, establishing high-quality quantitative data by which to evaluate criteria is time-consuming and costly. Use of too many criteria will increase MAE costs and timeframes without a clear benefit.

2.3.2 Avoid Duplication / Double-Counting of Criteria

Duplication of criteria or measuring strongly correlated criteria (e.g. evaluating both boardings and trips) may inadvertently add weight to the value of specific criteria without adding meaningful discriminatory benefit to the evaluation. The approach in the Phase 2 Evaluation was to qualitatively assign summary account scores informed by underlying criteria in order to evaluate each of the alternatives. There are some instances where there are correlated criteria in the Phase 2 MAE such as travel time in Transit User Effects and accessibility in Transit Network / System Access. Both of these criteria inherently measure travel time from origin to destination and could be seen as double counted.

2.3.3 Use Quick, Simple Initial Screening Criteria

Rather than taking a high number of project options through a full business case, it is generally advisable to pare down an initial list of potential options to a short-list of feasible options by implementing an initial review using high-level screening criteria which can often be expressed in a simple ‘yes / no’ or ‘pass / fail’ format. For example, it may be possible to dismiss certain options by assessing the number of residents / jobs within a given radius around the proposed transit line before undertaking detailed demand modelling.

2.3.4 Evaluation of Criteria During and Following Construction

Many MAEs evaluate only impacts that occur once operation of a new transit line begins. However, where possible, MAEs should also consider impacts during construction, such as travel time penalties imposed on traffic and transit passengers and emission of criteria air contaminants.

2.3.5 Valuation of Auto Operating Costs

Some MAEs use the full cost of auto operation (as estimated by the Canada Revenue Agency, or similar) when assessing the economic costs and benefits of a new transit line. Others use a fraction of the auto operating cost on the assumption that auto ownership will be steady under each option, and thus economic benefits of a given option are not tied to insurance, capital, and some maintenance costs of auto ownership. These MAEs typically do not consider passenger fare revenue as a benefit from an economic standpoint, but instead treat fare revenue as a transfer (and thus moot). (Fare revenue is typically considered in financial analysis).

More recently, Metrolinx (the transportation planning agency in the Greater Toronto and Hamilton Area) has completed economic evaluations which *do* count fare revenue as a project benefit, but as a trade-off, do *not* evaluate typical auto operating costs, instead only considering the auto operating costs which are assumed to be not perceived by the average user ($0.06 / km).

2.3.6 Clarity Around Ridership Estimates (and Other Criteria)

It is critical to be explicit and precise in describing what each criteria measures. For instance, some MAEs use 'boardings' as a measure of ridership; others use 'trips'. Whichever measure a MAE includes, its parameters need to be clear (e.g. describe trips as being linked or unlinked).

2.3.7 Use of Wider Economic Benefits in Project Evaluation

MAEs typically do not consider wider economic benefits (employment, tax, income, or GDP) resulting from construction and operation of a new transit facility, since these economic benefits are a result of government investment and will generally occur whether the investment occurs in Option 1, Option 2, or an unrelated (or even unproductive) project. However, wider economic impacts can be a critical benefit to rapid transit investment (see *Section 3.1*) and are thus a key consideration in investment decision-making as well as being of broader interest to stakeholders and the public.

2.3.8 Use of Simple, Relatable Metrics for Public-Facing Documents

Presentation of project benefits to the public should be simple and relatable. For instance, rather than describing total annual time savings for passengers of, say, three million hours, passenger time savings could be presented as, say, seven minutes saved per passenger trip.

2.3.9 Understanding Land Use is Critical but Challenging

While it is relatively straightforward to test the impact on demand for a new line under several service-frequency scenarios, estimating demand due to changing land use patterns is time-consuming and imperfect. Land use patterns have many degrees of freedom and can change as a result of new legislation, policy, economic conditions, development elsewhere in the municipality or region, etc. Land use assumptions should be conservative when estimating ridership and financial account criteria (such as tax revenue), but projects should allow for potential long-term growth in demand by increasing frequency, the number of vehicles per transit unit, or parallel service.

3. CONTEXTUAL ELEMENTS

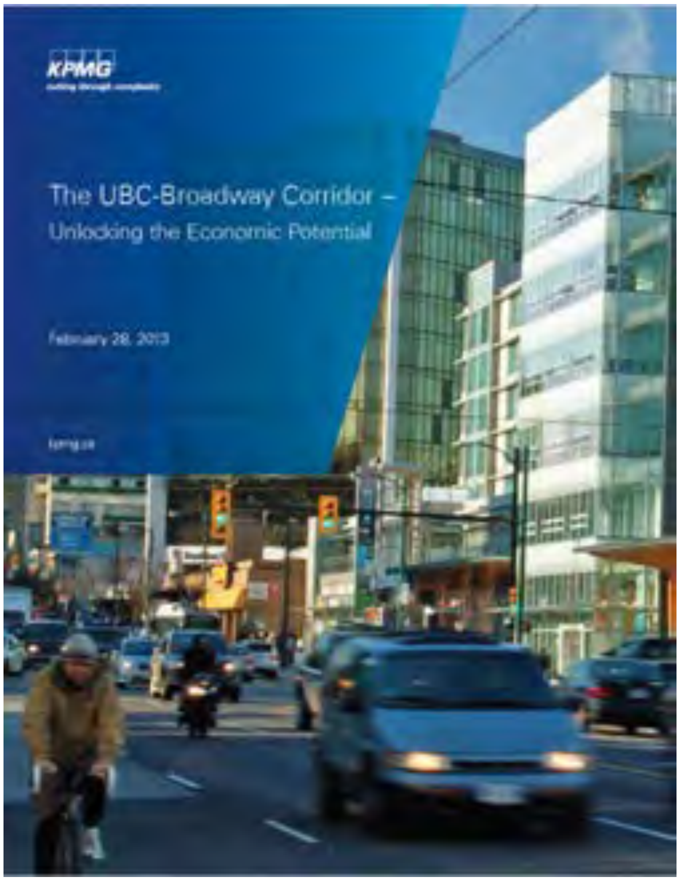
This section provides an assessment of more recent studies and the contextual elements that have changed substantially since the completion of the UBC Line Rapid Transit Study – Phase 2 Evaluation in 2012. Elements such as the political, socio-economic, policy and land use context have all changed, affecting the decision-making context and necessitating a review of underlying factors affecting planning of rapid transit services from Arbutus to UBC. Each section below concludes with implications for rapid transit planning in the study corridor. In addition, current land uses and demographics within the study corridor are discussed.

3.1 REVIEW OF KPMG AND ULI REPORTS

Since the completion of the Phase 2 evaluation in August 2012, several follow up studies conducted by the City of Vancouver and UBC, as well as other project partners, have supported the development of rapid transit along the Broadway / 10th Ave corridor. The focus of these studies has been economic development potential associated with rapid transit provision. A high-level summary of each and the relevance of findings from these reports is provided below.

3.1.1 KPMG Report: The UBC-Broadway Corridor – Unlocking the Economic Potential

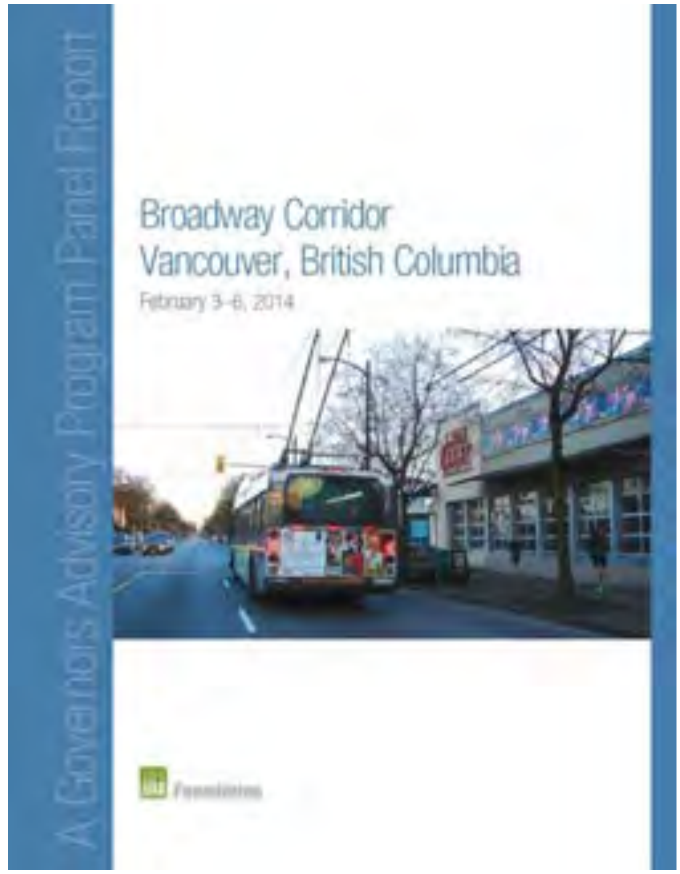
On behalf of the City of Vancouver and UBC, KPMG completed an economic assessment of developing a rail rapid transit alternative along the Broadway / 10th Ave corridor. The economic potential of connecting Vancouver to UBC includes the development of a technology hub, similar to Toronto's MaRS district, San Diego's CONNECT, or London's Tech City. The study considered that the Central Broadway area has the potential to foster a technology and health research hub, if a connection to research facilities to UBC could be completed. The assessment concluded that the significant planned growth at UBC and along Broadway cannot be realized unless a rapid transit system is developed. The study recommended that, in addition to an efficient and reliable transit system, an economic strategy is required to set a clear path to growth for technology companies through sharing of ideas, innovation and research.


KPMG

The UBC-Broadway Corridor –
Unlocking the Economic Potential

February 28, 2013

3.1.2 ULI Report: Broadway Corridor Vancouver – Readying the Urban Corridor for Growth



The Urban Land Institute's (ULI) Governors' Advisory Panel was commissioned by TransLink, government of BC, City of Vancouver, UBC and Metro Vancouver to review land use along the UBC-Broadway corridor and assess land development potential, best practices, ideal forms of future development, extent of development around stations, economic and social implications and trade-offs among different rapid transit modes. Some of the key findings include the following:

- Transit service along the existing corridor is insufficient;
- Future land use along the corridor should fit the profiles of the various neighbourhoods considering land uses, scale, density, and personality at street level.

The study suggests that the potential to develop the corridor will generate economic opportunities, but that community consensus as to how growth will shape the city is vital for success. The study concludes that a community outreach program and education process is required so that stakeholders understand the implications of rapid transit choice and how that relates to land development. Other successful programs have engaged the community through workshops that focus on phased development around stations.

3.2 SOCIO-ECONOMIC CONTEXT

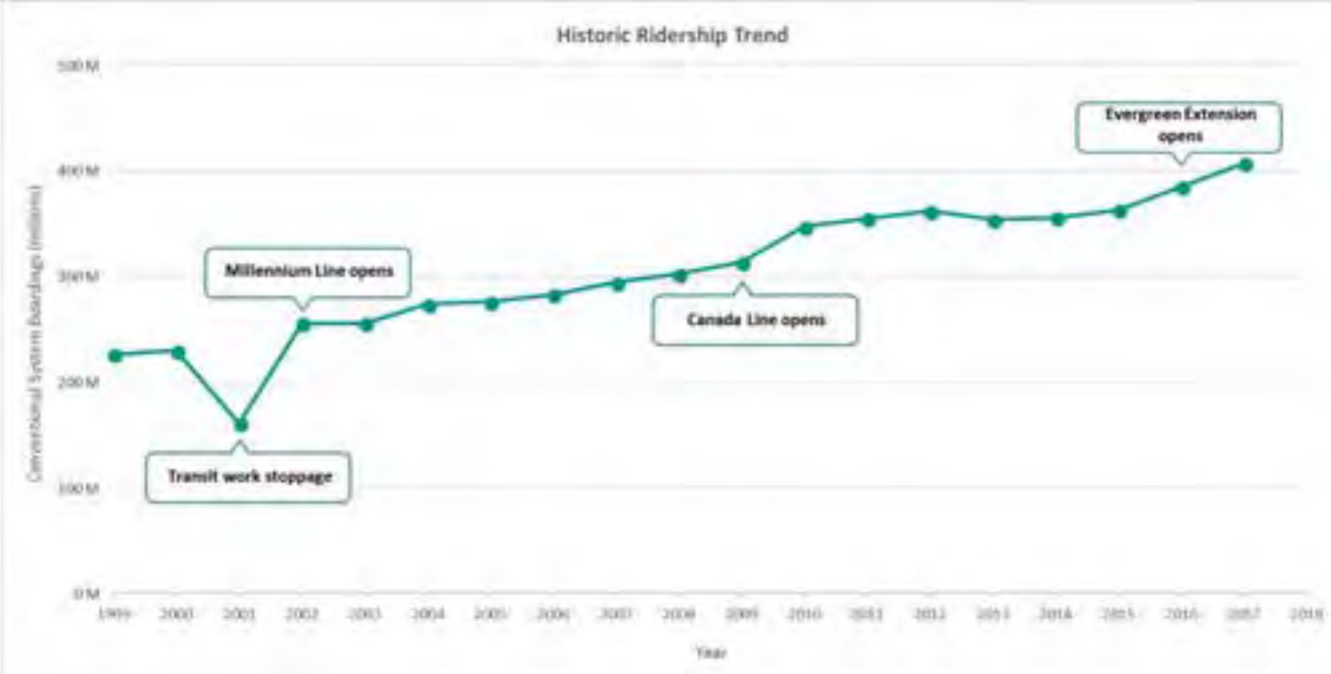
Some of the broader socio-economic factors have changed significantly since 2012 affecting the overall economy, incomes and the price for goods and services. This information also accounts for some of the underlying factors that affect people's choice to travel which will continue to change in the longer term planning horizon. These also speak to the uncertainty in predicting future conditions as the planning and development of a rapid transit alternative to UBC progresses.

3.2.1 Transit Ridership and Sustainable Mode Travel

Transit ridership continues to grow at a record pace over the past few years as shown in *Figure 3-1*. In 2017, the region saw over 400 million boardings for the first time in its history, which is a 5.7% increase over 2016 levels. Many factors have contributed to this increase in transit ridership:

- The Evergreen Extension was opened in December 2016 providing a 25% increase to ridership in the Northeast Sector;
- The provincial economy has been growing at a rapid pace with the lowest unemployment levels since the 2008 economic downturn;
- Fuel prices have been high shifting people from driving to taking transit; and
- Population and employment growth have resulted in a growing travel market.

Figure 3-1: Historic Ridership Trend in Metro Vancouver

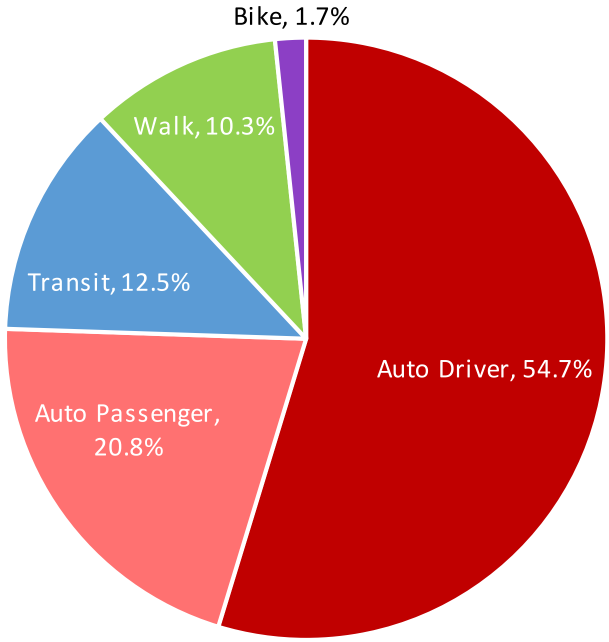


The 99 B-Line is the highest ridership bus route in the region with weekday average boardings at 56,600 in 2017. It is the highest ridership bus route in both Canada and the United States. About one third of revenue hours on this route operate in overcrowded conditions which is the highest level of overcrowding on all routes in Metro Vancouver. This level of overcrowding results in a significant number of pass-ups at bus stops.

As part of TransLink's Regional Transportation Strategy, a sustainable mode share target (walk, bike, and transit) of 50% has been established for 2045. *Figure 3-2* provides an estimate of the 2016 regional mode share with the sustainable mode share at 24.5%. The Evergreen Extension of the Millennium Line carries approximately 30,000[4] boardings on a daily basis which contributes approximately 0.5% of the regional sustainable mode share. Similarly, the Canada Line carries 138,700 daily boardings which contributes approximately 2.2% to the regional transit mode share. These ranges provide a benchmark for the level of contribution that the extension of rapid transit service to UBC, including RRT and LRT, could make to the regional transit mode share.

[4] *https://www.translink.ca/About-Us/Media/2017/February/Early-Evergreen-ridership-numbers-suggest-strong-start.aspx*

Figure 3-2: 2016 Estimated Metro Vancouver Mode Share



3.2.2 BC Economy

The prevailing socio-economic conditions at the time that the Phase 2 study was being prepared were substantially different to today. In 2012, BC's economic growth was amongst the weakest in Canada at just 1.7 % per annum, while growth sectors included residential construction, engineering, mining, oil and gas.

In 2017, real GDP growth of 3% is anticipated to remain steady in the coming years, while the average exchange rate of ~C$0.78 to the US dollar has supported growth in exports, and in the tourism, film, technology and business sectors in BC. The strong economy and employment act as a boost for housing and employment demand across the region. While the economic outlook in 2017 and beyond is more positive than in 2012, the exchange rate and lower value of the Canadian dollar could affect construction cost estimates which are likely to be higher given the weaker Canadian exchange rate.

3.2.3 Fuel Prices

The price of crude oil in 2012 was generally above the $100 / barrel mark, whereas in 2017, it has remined below $60 / barrel. However, gas prices at the pump, which provide a high-level indicator of peoples' preference for transit, are much the same as they were in 2012, ranging between ~$1.20 / litre to $1.40 / litre, see *Figure 3-3*.

Figure 3-3: 96 Month Average Retail Gas Price (2010 to 2017)

IMPLICATIONS

- While buoyant economic growth provides a positive context for transit investment, the rate of exchange could result in increased construction costs relative to those assumed in 2012

3.2.4 Housing Affordability

In 2012, the average price of a detached house in Metro Vancouver was $904k[5] (*Figure 3-4*). This equated to 13 times the median Metro Vancouver family income of $71k[6]. The average rental vacancy rate in 2012 was 1.8%[7].

By comparison, the average house price of a detached house in Metro Vancouver had increased to $1.3 million[8] by November 2017: 19 times the Metro Vancouver (2016) median family income of $73k[9], as illustrated in *Figure 3-5*. Detached homes now are well beyond the economic reach of most families in Metro Vancouver, while rental vacancy rates in 2017 are less than 1%[10] (and lower than 0.5% in the City of Vancouver).

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[5] Real Estate Board of Greater Vancouver, see: http: / / www.rebgv.org / sites / default / files / 201212_REBGVStatsPackage.pdf
[6] http: / / www.statcan.gc.ca / tables-tableaux / sum-som / l01 / cst01 / famil107a-eng.htm
[7] Canada Mortgage and Housing Corporation, see: https: / / www.cmhc-schl.gc.ca / en / hoficlincl / homain / stda / data / data_004.cfm
[8] Real Estate Board of Greater Vancouver, see: http: / / www.rebgv.org / home-price-index?region=all&type=Detached&date=2017-11-01index?region=Greater+Vancouver&type=Detached&date=2017-11-01
[9] http: / / vancouversun.com / news / local-news / growth-across-the-board-in-b-c-income-and-households-stats-can
[10] Canada Mortgage and Housing Corporation data

Figure 3-4: $1M Single Family Residential Properties in Metro Vancouver, 2012

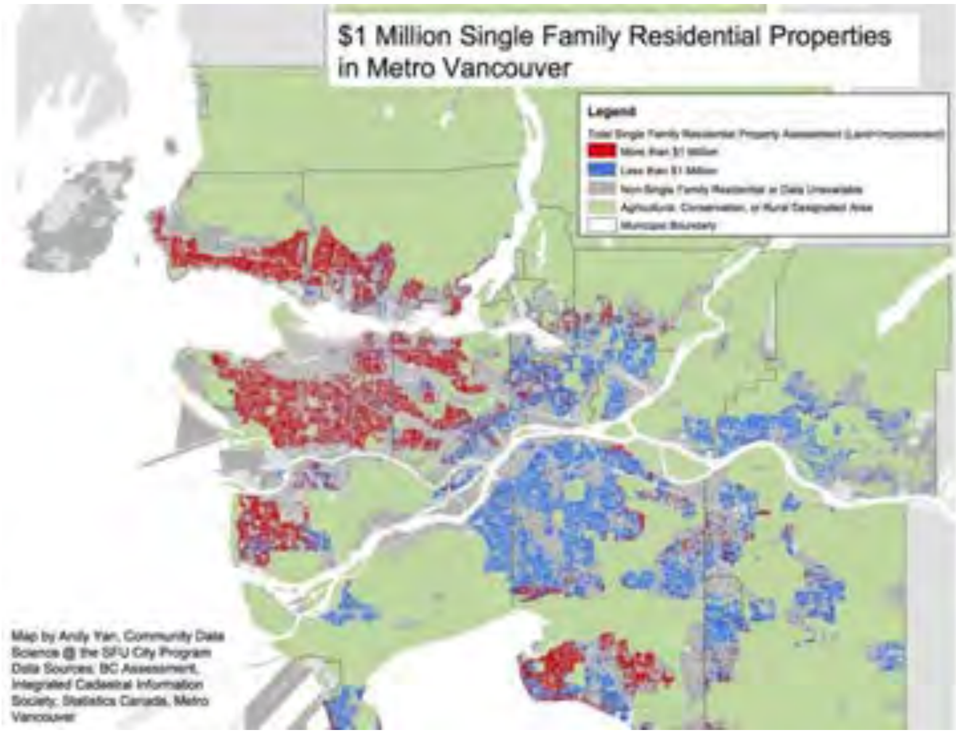
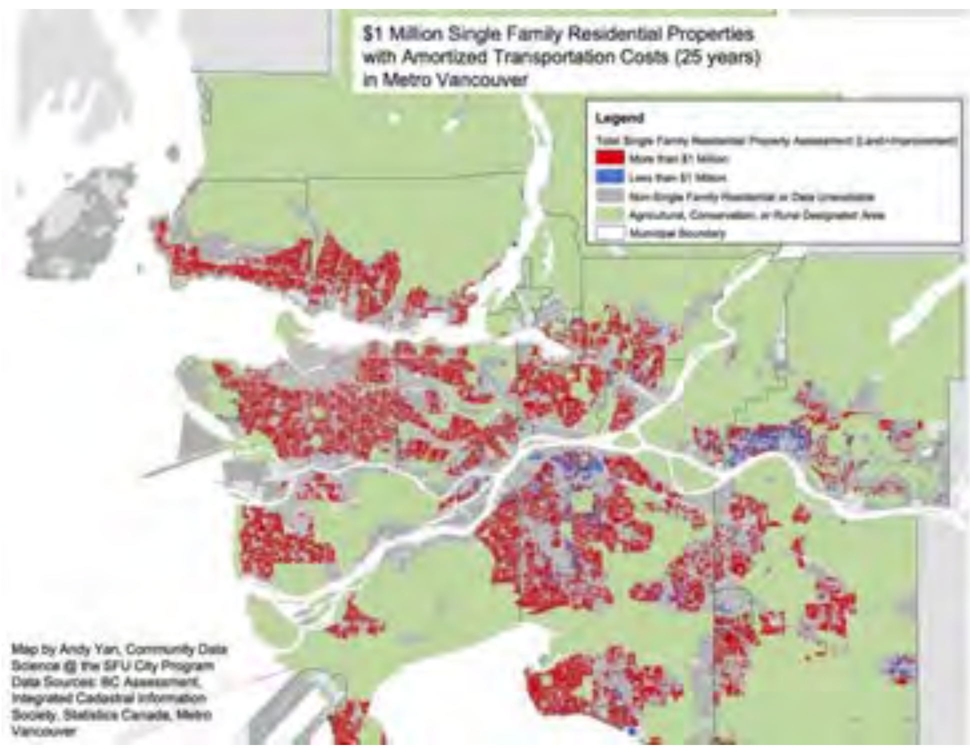


Figure 3-5: $1M Single Family Residential Properties with Amortized Transportation Costs (25 years) in Metro Vancouver, 2016



Research undertaken by the Simon Fraser University (SFU) indicates that detached family homes in Metro Vancouver valued at $1 million or more[11] tend to be located in Vancouver, Burnaby, Richmond, the North Shore, and parts of South Surrey. However, when the amortized costs of transportation are considered, the costs of almost all detached family housing across Metro Vancouver are greater than $ 1million.

It is estimated that by 2020, workers in 82 of 88 in-demand jobs will be unable to afford a single-family home in Metro Vancouver and, in just 10 years, most people will forgo career opportunities in the region and simply relocate elsewhere.[7]

Both the (un)affordability of single-family homes, the cost of transportation and rental (un)availability point to the need for affordable multi-family housing, that is well located relative to transit services, and includes rental opportunities.

3.2.5 Construction Cost Escalation

Since 2012, the Canadian dollar has declined relative to the US dollar as shown in *Figure 3-6* below. This coupled with favourable economic conditions in BC has led to construction cost escalation necessitating a review of construction costs for each of the rapid transit alternatives.

Figure 3-6: USD – CAD Exchange Rate 2012 to Present

IMPLICATIONS

- Transit oriented development and the potential for the provision of well-located affordable family housing are critical to the region's economy
- Evaluation criteria to include transit-oriented development potential west of Arbutus
- Construction costs need to be updated to reflect escalation

[11] See: http: / / vancouversun.com / news / local-news / experts-take-on-b-c-s-housing-affordability-crisis-at-annual-ubcm

3.3 POLICY CONTEXT

TransLink's Regional Transportation Strategy (RTS) was finalized in 2013, subsequent to the completion of the 2012 study. The RTS goals emphasize sustainable transportation choices; a compact urban area; safe, healthy, and complete communities; a sustainable economy; and environmental protection. The RTS also sets out high level targets, which include increasing transit, cycling and walk mode share to 38% by 2030, and to 50% by 2045, while reducing vehicle kilometres travelled (VKT) by one third over 2011 levels.

3.3.1 The Mayors' Council Vision

In 2014, the Metro Vancouver's Mayors' Council established their 10-Year Vision for Metro Vancouver Transit and Transportation. This vision outlined the investments and actions to be pursued over the following 10 years. TransLink is now delivering this vision through a series of phased Investment Plans:

- Phase 1 (2017-2026): increases in conventional bus services, funding for walking, cycling, road infrastructure (approved in November 2016)
- Phase 2 (2018-2027): rapid transit construction, including BSP which has now been approved
- Phase 3 (2020-2029): additional transit service increases

The Vision also sets the course for the introduction of Mobility Pricing. The Mobility Pricing Independent Commission completed its assessment of pricing alternatives in May 2018 which will help to frame the future of mobility pricing in the region. The purpose of the Commission is to make recommendations to the TransLink Board of Directors and Mayors' Council on how to improve the way transportation in Metro Vancouver is priced, in order to manage congestion, promote fairness, and support continued investment in urgently needed transportation infrastructure.

3.3.2 City of Vancouver Transportation 2040

The City of Vancouver's Transportation 2040 plan (2012) was well underway at the time of the 2012 study. Nevertheless, it is worthwhile noting some of the Plan's key precepts here. Mode share targets for Vancouver, as set out in the Plan, are similar to those in the RTS recognizing that Vancouver generally has higher transit and sustainable mode travel than other parts of the region. By 2020, the City of Vancouver aims to achieve a 50% transit, walk or bike mode share for all trips. This target increases to 2 / 3 (66.7 percent) of all trips by 2040. Other objectives and targets include:

- Reducing the distance driven by residents by 80% (compared to 2007)
- Locating major trip generators near transit
- Advancing rapid transit, and supporting integration with other modes
- Reducing emissions
- Protecting areas for future transit stations

In March 2016, the City of Vancouver purchased the Arbutus corridor from Canadian Pacific Railway in order to preserve it as a walking and cycling greenway for residents. The City also has a longer-term vision of developing a streetcar network along this corridor to connect downtown Vancouver with the Marpole community. A connecting station is envisioned at Broadway that would need to be integrated with the Broadway Subway Project.

3.3.3 UBC Transportation Plan

UBC developed their Vancouver campus plan in 2014 providing a guiding document for transportation objectives and targets. Transportation is a key element of campus planning which supports sustainable transportation options for the university community. Over the past couple of decades UBC has implemented significant changes to transportation including restricting the supply and increasing the price of parking, implementing the student U-Pass program and increased transit service which has resulted in a significant shift from auto to transit mode shares.

The campus is envisioned to grow and develop over the next few decades and UBC has set ambitious targets including:

- By 2040 at least two-thirds (66.7 percent) of all trips to and from UBC will be made by walking, cycling or transit;
- Maintain at least 50% of all trips to and from the campus on public transit;
- Reduce SOV travel to and from UBC by 20% from 1996 levels;
- Maintain at least 30% reduction from 1997 levels in daily SOV trips per person to and from UBC; and
- Maintain daily private automobile traffic at or less than 1997 levels.

These targets are to be achieved through implementation of walking, cycling, transit and driving policies and actions including development of new facilities such as a walking network, cycling network and transit network. The plan states that UBC is *committed to advancing improvements to the local and regional transit network* including *advocating for expanded transit service to the campus, with the goal of implementing rapid transit to UBC*.

IMPLICATIONS

- The RTS and Mayors' Council Vision established a phased approach to implement rapid transit along the Broadway corridor, starting with BSP to Arbutus
- Ambitious mode share and VKT reduction targets support rapid transit investment along the Broadway corridor, as well as high density, mixed use transit-oriented development
- Plan objectives and targets inform concept planning and evaluation criteria which should include: mode share impacts, transit integration potential, integration with other modes, urban development potential, VKT impacts, emissions reductions
- Concept planning should include careful consideration of capturing existing (and future) trip generators within station catchments, transit / active mode integration, protection of future station areas
- All partner agencies have recognized the need to extend rapid transit from Arbutus to the UBC campus which will help achieve each of their mode share and VKT targets.
- The scale and complexity of development at UBC would warrant a review for a potential second station to serve the south end of campus. This area is expected to grow and densify over the next several decades which would benefit from being well served by rapid transit.
- A long-term view, beyond the horizon of forecast land use to 2045, is warranted since any rapid transit built along this corridor will be around for many generations

3.4 LAND USE CONTEXT

Since 2012, several land use changes have occurred, which were not considered in the 2012 analysis. In particular:

- **Jericho Lands:** In 2014 the MST Partnership (consisting of the Musqueam, Squamish and Tsleil-Waututh First Nations) and Canada Lands Company entered into an agreement to redevelop Jericho Lands East (21 ha). In 2016 the MST Partnership also acquired Jericho Lands West (15ha). Details of the proposed development on the 36-ha site located between 4th Ave and 8th Ave, west of Highbury Street, are still to be agreed. However, it is likely that the development will include high density residential uses. Note that this growth is not reflected in the land use assumptions of the modelling work undertaken in this study. The City is undertaking a comprehensive planning program over the next two years to develop a Policy Statement for these lands.
- **Musqueam "Block F" development:** construction of a 8.7 ha development (on a greenfield site located on University Boulevard and bounded by Acadia Road, Toronto Road and Ortona Avenue) has begun. The development will house 2,500 residents and include a community centre, 30,000 sq ft of commercial development and neighbourhood park. The development is located approximately 900m from the UBC Station proposed in the 2012 study. A future station was assumed adjacent to the site on University Boulevard east of Toronto Road but this was not included in project costing or evaluation.

- **University Golf Course Lands:** These lands (totalling approximately 59 hectares) were transferred to the Musqueam in 2008 (along with the "Block F" site identified above). The agreement requires the band to keep a golf function in place until 2083, after which the site will be available for redevelopment. The proposed alignment identified in the 2012 study traverses the golf course. However, much of the golf course is outside of the walk-up catchment for station locations proposed as part of that study. Provision for a future station within the golf course lands should be considered to enable longer term redevelopment.
- **UBC Land use planning:** UBC Campus & Community Planning is currently exploring the extent to which rapid transit may enable identified neighbourhood plan areas to accommodate additional residential development beyond what is currently approved in the UBC Land Use Plan. Their working assumption is that 10-15% more units could be assumed in a "rapid transit" scenario.

IMPLICATIONS

- New developments, including transit-oriented development opportunities and new ridership potential should be taken into account in alignment and station location considerations and analysis.
- Potential for additional stations as a result of new developments proposed should be included in analysis and evaluation of alignment and station locations.
- Potential land allocations for future stations to be included in concept plan, and long-range ridership forecasts.

3.5 DEMOGRAPHICS

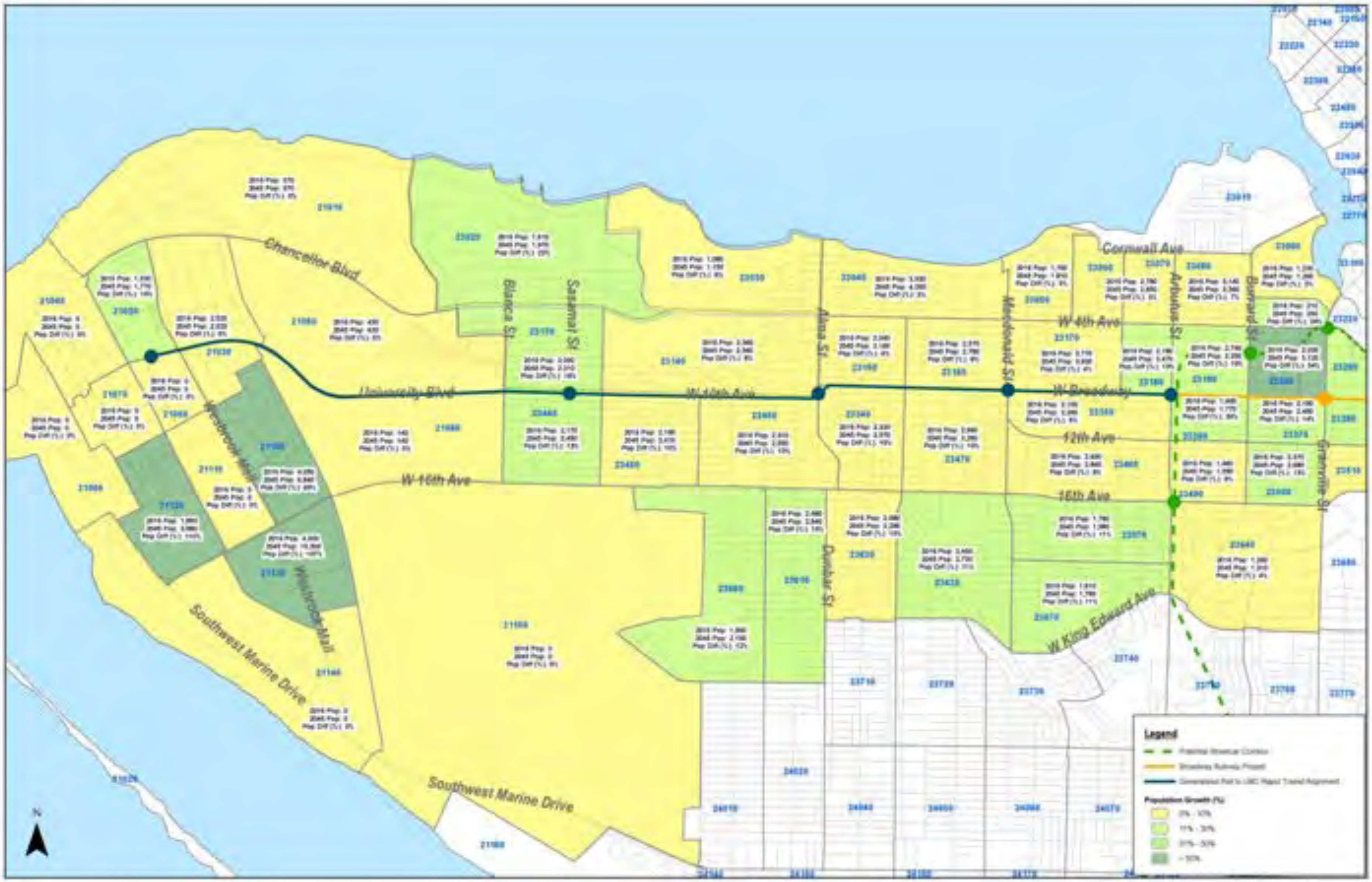
According to Census 2016 estimates, the existing population within the boundaries of the study area is close to 100,000 people. (Note that this excludes students living in residence on UBC campus, which totalled ~12,000 in 2017.) Population projections developed by Metro Vancouver, in consultation with the City of Vancouver and UBC planning staff, suggest that the total corridor study area will see an overall ten percent growth in its population by the year 2030, as shown in *Table 3-1*. These land use assumptions do not include changes (such as densification) as a result of the rapid transit line and are considered conservative as they do not include development of the Jericho Lands. Much of that growth is projected to occur in areas within the UBC district, predominantly in Wesbrook Village and the areas bounded by East Mall, Agronomy Road, Wesbrook Mall, and Marine Drive. As shown in *Figure 3-7*, the area to the north of 16th Avenue, west of East Mall, will see the highest rate of growth with approximately 2,000 new residents. Modest increases in population are projected for the areas north and south of the Broadway Corridor. Note that although it is anticipated that the Jericho Lands will experience substantial growth with the planned redevelopment of this property, this growth was not reflected in the land use assumptions of the modelling work undertaken in this study due to the uncertainties regarding the future development plans for this site.

Employment totals are expected to remain relatively stable between 2016 and 2030. Growth in job opportunities will be concentrated at UBC, as seen in *Appendix A*. It is anticipated that the total number of households within the study area will grow by 10 percent by the year 2030. Increases in the number of households will primarily occur in the Endowment Lands and areas within UBC, while decreases are expected to occur east of Wesbrook Mall.

Table 3-1: Population, Employment, and Household Projections for the Study Area

Projections						
Totals	2016	2030	2045	Growth from 2016 to 2030	Growth from 2030 to 2045	Growth from 2016 to 2045
Population	97,850	107,400	117,400	10%	9%	20%
Employment	65,700	70,000	72,650	7%	4%	11%
Household	47,250	51,800	56,450	10%	9%	19%

Figure 3-7: Projected growth in population from 2016 to 2045



Source: RTM 3.2 Land Use Assumptions from Metro Vancouver (May 2018)

DRAFT

4. RAPID TRANSIT PLANNING BEST PRACTICES & BENCHMARKS

This Rapid Transit Planning Best Practice Review was completed in order to understand challenges encountered during the planning, procurement, and construction phases of rail-based rapid transit lines, and solutions for overcoming these challenges early in the planning stages. The review focused on case studies of rail-based rapid transit lines (including phased construction and extensions) in Canada and the United States and included the following relevant features:

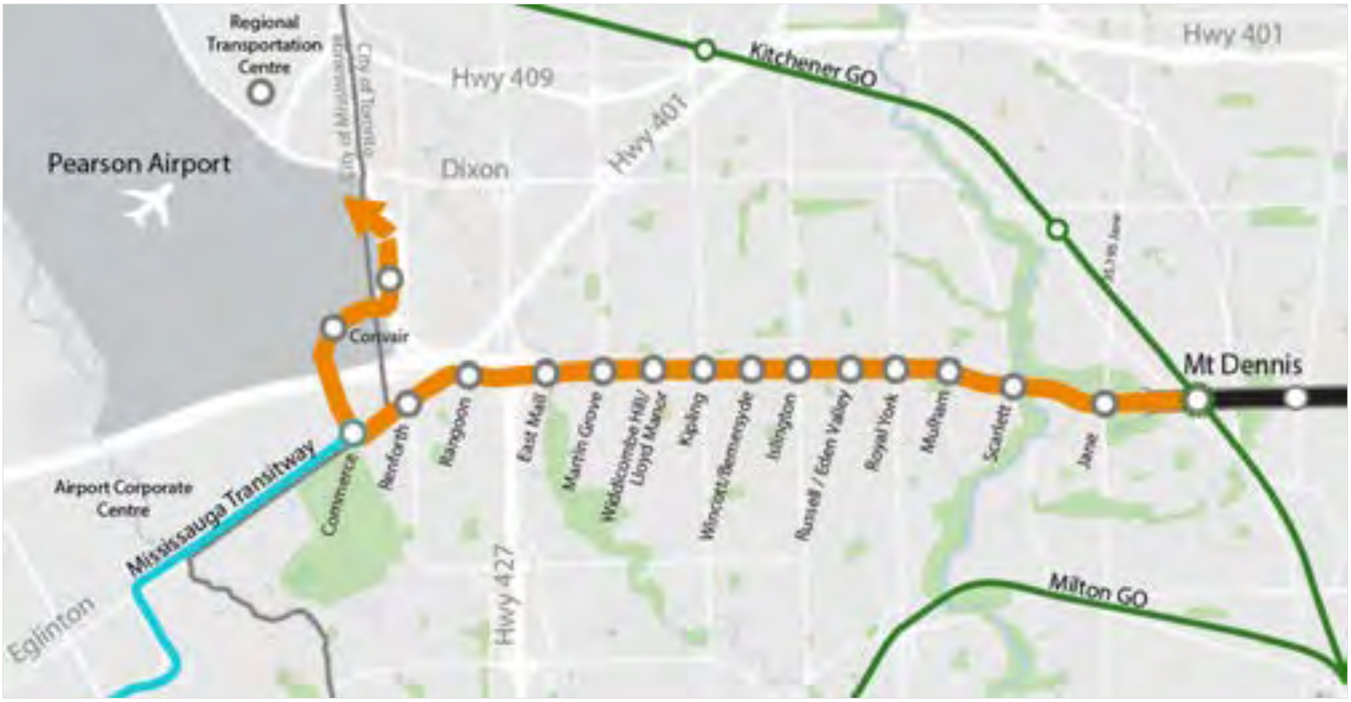
- Connection to a special generator such as an airport or university campus;
- Elements of surface running and grade-separated operation;
- Built in a similar urban setting / context such a major commercial corridor;
- Similar scale in terms of line length, number and spacing of stations and capital cost;
- Network demand modelling to forecast ridership including MAE with clearly defined goals and objectives;
- Similar service characteristics in terms of headway, line time and capacity; and
- Phased planning and construction of extension.

A review of Multiple Account Evaluation (MAE) processes was also undertaken. Recommendations pertaining to transit planning best practices, including MAE business case recommendations, are included.

4.1 CASE STUDY 1: TORONTO EGLINTON CROSSTOWN WESTERN EXTENSION

The Eglinton Crosstown (ECLRT), shown in *Figure 4-1*, is a 19km, 25-stop LRT line currently under construction in Toronto, scheduled to begin operation in 2021. As of March 2016, Toronto City Council has approved eastern and western extensions to the line. This review of the ECLRT focuses on the Western Extension, also known as the Eglinton West LRT (EWLRT), which would see 8-12 new stations built between Mt. Dennis (western terminus of ECLRT) and Pearson International Airport, which is located in Mississauga. A fully at-grade EWLRT is estimated to cost $1.5 to 2.1 billion, with grade separation adding $0.9 to 1.3 billion to the total cost.

Figure 4-1: Toronto Eglinton Crosstown Western Extension Alignment and Stations



A business case comparing different transit options for the EWLRT examined use of below-grade LRT service, above-grade LRT service, at-grade LRT service, and combinations therein, as well as a BRT option. The project has many stakeholders, including the Toronto Transit Commission, Metrolinx, MiWay (Mississauga Transit), City of Toronto, City of Mississauga, Pearson International Airport (Airport Authority), as well as local residents and businesses. As a result, several competing proposals for different technologies, numbers of stops, grade-separation strategies, etc., were put forward by different stakeholders.

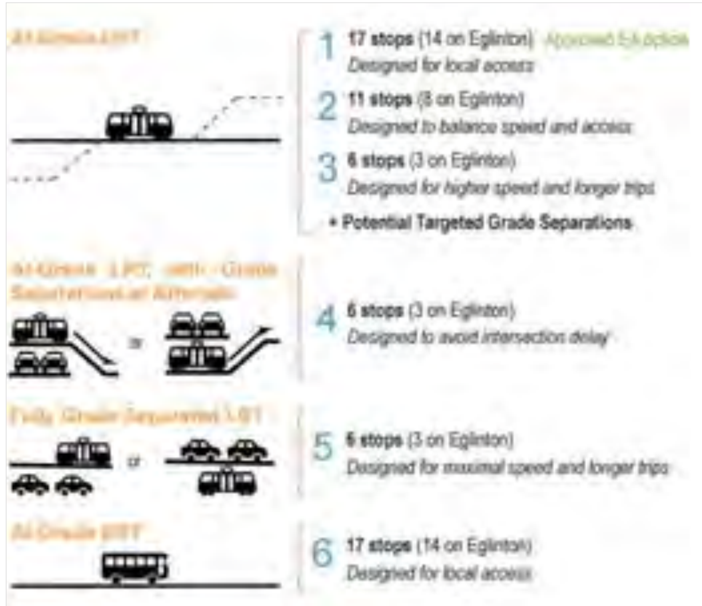
4.1.1 Evaluation Process

The business case for EWLRT used an evaluation framework with a balance of transportation, economic, financial, environmental, and social equity inputs, based on policies in Toronto's Official Plan. The evaluation framework used the same Evaluation Accounts as the Phase 1 (ECLRT) project; however, the list of evaluation criteria was expanded to incorporate performance measures not included in Phase 1. Evaluation frameworks from different stakeholders were blended to complete a detailed study of the higher performing options, leveraging local land use expertise of City Planning.

4.1.2 Key Findings

Because Pearson International Airport is a major trip generator and is located at the proposed terminus of the EWLRT, economic analysis of the different EWLRT options favoured a high-speed service with few stops. However, the strategic component of the business case valued more stops to in order to better support community access and urban intensification goals.

Figure 4-2: Rapid Transit Alternative Configurations



The choice to pursue LRT technology instead of BRT technology was informed by transfer volumes, network trip patterns, and ridership projections estimated through detailed transportation demand modeling. In particular, the time penalty for passengers transferring from one vehicle to another – which would be required if BRT technology were selected for the EWLRT, but not if LRT technology was selected – was found to be prohibitive, creating a low-scoring economic evaluation for BRT options.

The EWLRT business case involved extensive cooperation between project partner agencies to integrate analysis, harmonize model outputs, and leverage different expertise in order to ensure that unified information was presented by staff to various levels of government. The harmonized business case recommended at-grade LRT service be pursued, providing better access for transit users, reduced environmental impact, and a better cost-benefit analysis relative to grade-separated options. However, as of December 2017, Toronto City Council has voted to re-examine the case for tunneling or other grade-separation strategies. The decision to pursue an additional study came as a result of concern from local residents and businesses that traffic would be impeded by an at-grade LRT line, though analysis showed that traffic signal coordination along the EWLRT corridor would mitigate most traffic impacts of at-grade service. The outcome of the additional study will not be available until 2018.

LESSONS LEARNT & IMPLICATIONS

- Like UBC, Pearson Airport, is a major trip generator located at the proposed terminus of the Rail Rapid Transit line. In such a context, a high speed, limited stop service generates the greatest economic benefit.
- The lack of consistent technology along the corridor length necessitates passenger transfer and involves a time penalty which significantly undermines the benefits of transit investment. Consistent technology along the length of the Broadway Corridor would provide greater economic benefits.
- Concerns with at-grade operation and impacts to traffic, parking and businesses.

4.2 CASE STUDY 2: OTTAWA CONFEDERATION LINE

The Confederation Line (CL), shown in *Figure 4-3*, is a 12.5km, 13-stop east-west LRT currently under construction in Ottawa. Operation is scheduled to begin in 2018. Roughly one-quarter of the line, the portion in the central business district, will be below-grade. The project cost is approximately $2.1 billion. As of 2013, a second phase of work was approved, adding eastern and western extensions to the CL, as well as extending the Trillium Line (TL), an existing north-south LRT line in Ottawa. The CL extensions are being completed largely within the existing right-of-way used by an existing BRT service which is being replaced by the LRT extension. Phase 2 is currently in the procurement process and is expected to cost $3-billion.

This best practice review focuses on both project Phases 1 and 2. Phase 1 was procured under a Design-Build-Finance-Operate-Maintain (DBFOM) model, while Phase 2 is being procured under a Design-Build-Finance-Maintain (DBFM) model.

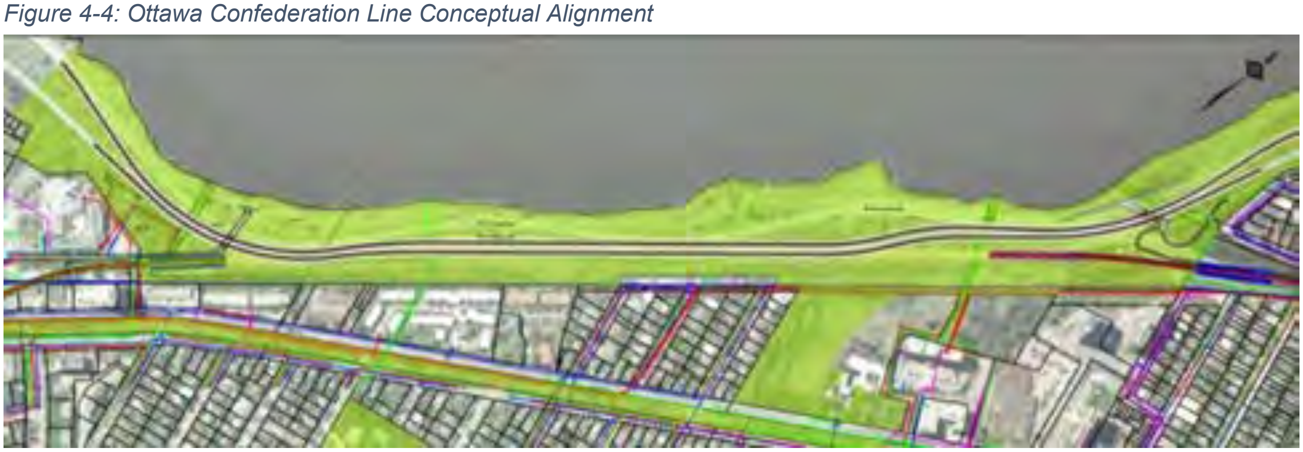
Figure 4-3: Ottawa Confederation Line Alignment and Stations

4.2.1 Evaluation Process

Phase 2 was planned following a comprehensive transportation master plan review which identified a bundle of rapid transit projects to proceed simultaneously as part of an 'affordable network', intended to accelerate the timelines of previous transit plans. The majority of the Phase 2 plan was established through functional design and a special transit project environmental assessment process.

A comprehensive business case looked at Environmental, Economic, Transportation and Strategic considerations for Council approval, comparing the base case ('business as usual') to the build case.

Figure 4-4: Ottawa Confederation Line Conceptual Alignment



4.2.2 Key Findings

Complications arose surrounding procurement of Phase 2 as a result of the P3 contract for Phase 1 of the CL. The consortium selected for Phase 1 had a significant advantage compared to competing consortiums regarding procurement of Phase 2 due to economies of scale for line operation and maintenance, as well as project-specific knowledge and other details. As a result, other consortiums were not initially interested in pursuing bids for Phase 2. To avoid sole-sourcing the entire Phase 2 work from the Phase 1 consortium, Ottawa was obliged to sign a $492-million Memorandum of Understanding with the incumbent consortium, under which the incumbent will provide operations and maintenance on Phase 2 but will abstain from bidding on the Design-Build-Finance portion of Phase 2.

An intergovernmental working group was created and assigned a 100-day mandate to resolve disputes related to natural heritage on specific parcels of land along the Phase 2 corridor in order to avoid slowing down the alignment selection process for the western extension of the CL. Additionally, following public consultation and Ottawa City Council input, one station was added to the proposed alignment in order to optimize bus transfers and operations.

Rather than studying the full set of alignment and technology options under a full business case framework, the initial functional design review and environmental assessment process was able to narrow down the potential options to a single preferred business-case option. Using this initial screening of each proposed option enabled Ottawa to focus the business case on the preferred alignment without spending resources exploring in detail options which were expected to perform poorly.

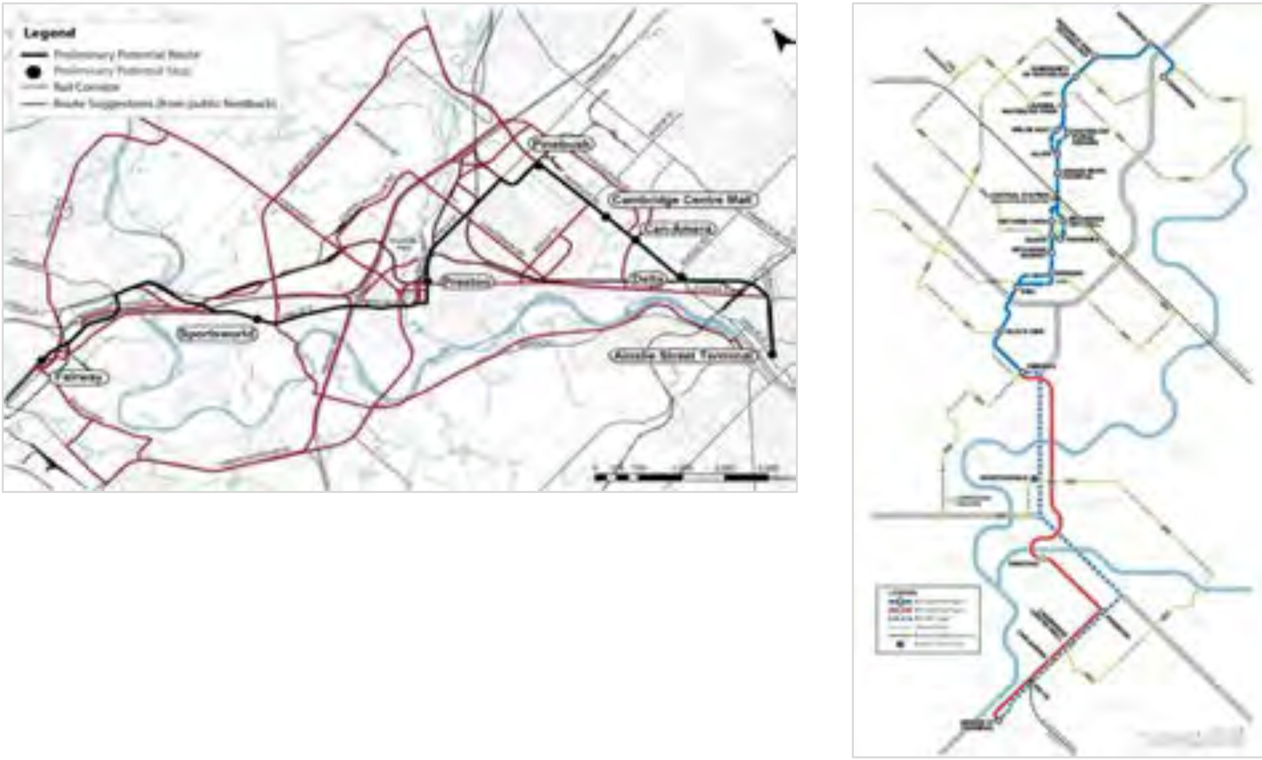
LESSONS LEARNT AND IMPLICATIONS

- An initial screening and evaluation process should be used to refine the potential options to a single preferred option for which a detailed business case should be developed.
- In order to get competitive bids and to get best value for money, procurement for an extension of the BSP should consider the competitive advantage that the consortium who is awarded the BSP extension to Arbutus will have. If SkyTrain technology is chosen, then this could be a disadvantage in terms of getting competitive bids from design-build teams.

4.3 CASE STUDY 3: WATERLOO ION LRT

Phase 1 of the Waterloo ION is a 19km, 19-stop LRT line currently under construction in Waterloo, ON, set to begin operation in April 2018. The LRT will run from Fairway Park mall (Kitchener) north to Conestoga mall (Waterloo), connecting two of the urban centres of the regional municipality, and three university campuses. Phase 2 of the ION, approved by the Region of Waterloo Council in conjunction with Phase 1, would see the addition of an 18km extension connecting from Fairway Park mall to Cambridge in the south. The alignment and number of stops to be included in Phase 2 has not yet been determined. Capital costs of Phase 1 of the project were approximately $820 million, and capital costs for Phase 2 are estimated to be roughly $1.1 billion.

Figure 4-5: Waterloo ION LRT Alignment and Stations



4.3.1 Evaluation Process

Phases 1 and 2 were approved simultaneously by the Regional Council with the intention of beginning construction on Phase 2 immediately following completion of Phase 1. However, the decision to proceed with Phase 2 was subject to an environmental assessment, launched following the initiation of Phase 1 construction, and dependent on further capital funding as well as consultation with the public and stakeholders.

A preliminary alignment for Phase 2 was identified at the time of approval in conjunction with Phase 1, under the principle of maintaining the general stop locations while providing flexibility to identify the best alignment during more detailed planning. The evaluation criteria being used for Phase 2 are the same standardized evaluation criteria used under Phase 1, based on the balance set out in the Regional Official Plan reflecting community and transportation objectives under the following categories: economic, transportation, social / cultural, and natural environment.

Following identification of the preferred route, the project team will advance detailed design, prepare environmental assessment documentation, and produce a full business case for approval by the Regional Council.

4.3.2 Key Findings

The ION was envisioned as a two-phase project from the time of its conception, enabling the Region of Waterloo to construct the most-needed section of the line without requiring funding for the full project, while ensuring that Phase 1 was built with consideration for the approximate route of Phase 2. Moreover, having split the project into two phases has provided an opportunity to review the successes and failures of Phase 1 – expected to be the highest ridership section of the line – before fully committing to Phase 2.

Extensive options development and consultation with local communities allowed for detailed understanding of challenges and opportunities at specific sites, and collaboration between local planning authorities sought to identify land development intensification potential. Rigorousness of the evaluation framework was developed through public consultation and by basing the evaluation framework within statutory public planning documents such as the Region's Official Plan.

Though Phase 1 was originally scheduled to begin operation in September 2017, delays in the vehicle delivery schedule necessitated a delay of operations until April 2018. This leaves the Region with a choice to make during the Phase 2 procurement process: the Region could select the incumbent vehicle provider (Bombardier) to provide the vehicles for Phase 2, arguably risking late delivery or cost overruns, or the Region could select a different vehicle manufacturer, but lose the efficiency associated with operating, maintaining, and procuring a single fleet.

LESSONS LEARNT AND IMPLICATIONS

- The technology, preliminary alignment and generalized station should be identified during initial planning, while allowing the flexibility to refine alignment and station location during detailed planning and design.
- Dividing the project into two phases supports staged funding and enables the opportunity to learn from the successes and failures of Phase 1 when embarking on Phase 2.
- Collaboration between local planning authorities enabled the rigorous and coherent identification of development intensification potential and facilitated integrated approach to transit and land use planning, supported by official planning documents.

4.4 CASE STUDY 4: LOS ANGELES PURPLE LINE EXTENSION

The Metro Purple Line, shown in *Figure 4-6*, is a 10km, 8-stop heavy rail line in Los Angeles, California. The line began operation in 1993 and runs from Union Station in LA's central business district west along a primary regional commercial corridor, terminating at Wilshire Blvd. and Western Ave. in Koreatown. The Purple Line is currently undergoing a three-phase, 7-stop 14.5km extension to the west. The project was split into three phases with independent construction timelines in response to funding availability and local design complications. Phase 1 of the three-phase extension is currently under construction, while sections 2 and 3 have received funding through ballot measures and winning federal grant programs. The total cost for the three-phase extension is estimated to be 6.3-billion USD.

4.4.1 Evaluation Process

Transit capital projects in the US applying for Federal Transit Administration (FTA) capital funding must follow a standardized evaluation and application process. The FTA evaluation process (called an Alternatives Analysis) focuses on a project's contribution to meeting strategic goals of existing regional and state plans; anticipated performance measures, in terms of transportation performance (passenger time saved, number of passengers, etc.) and cost-effectiveness; and environmental and social considerations.

Within the Alternatives Analysis framework, project criteria are typically framed within a 'goals and objectives' analysis rather than a MAE analysis. Typically, a vision statement is provided, and then several goals are stated (e.g. 'Mobility Improvement'), and each goal is assessed using 4-6 objectives (e.g. 'Reduce transit travel times') that are measurable and lead directly to evaluation criteria.

The intention is to promote a standardized evaluation process familiar to large transit agencies, state and federal officials, and consultants.

Figure 4-6: Los Angeles Purple Line Extension Alignment and Stations

4.4.2 Key Findings

Phase 2 of the Purple Line extension was challenged by well-resourced opponents of the alignment in Beverly Hills, leading to extensive lawsuits. Splitting the project into three phases enabled Los Angeles to maintain project momentum by securing smaller funding commitments and proceeding with planning for Phases 1 and 3 while Phase 2 disputes were settled. Tying delivery of the project to Los Angeles's bid for the 2024 Olympics served to accelerate the planning process; however, Los Angeles was subsequently selected to host the Olympics in 2028 rather than 2024.

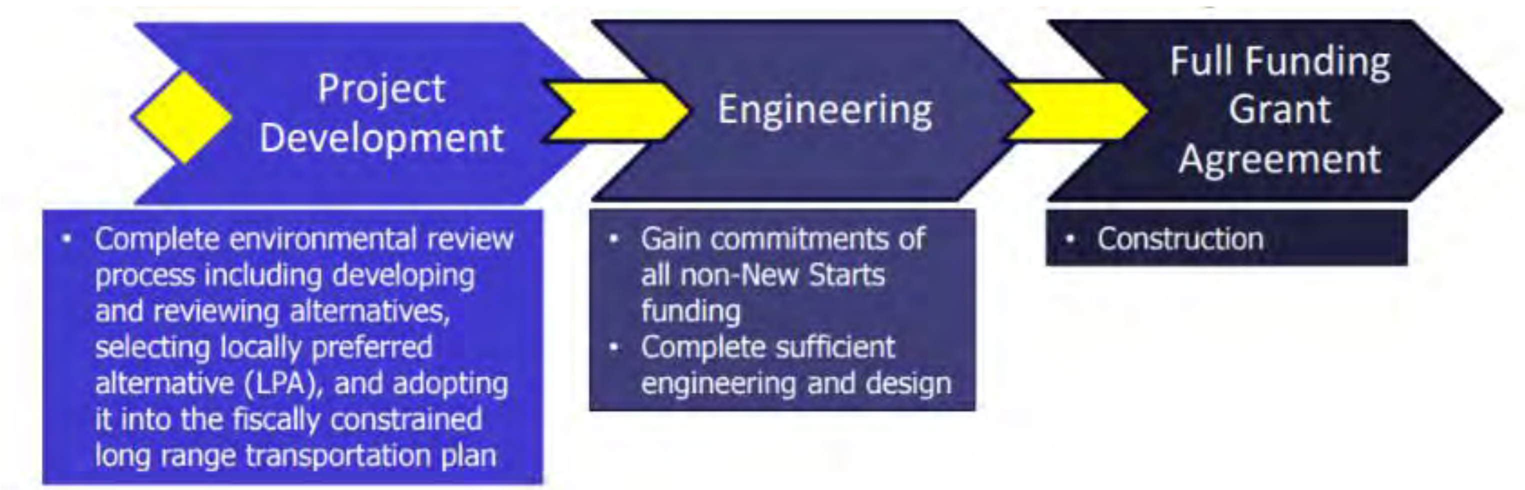
There are several advantages to using a standardized Alternatives Analysis (AA) / MAE process. The standardized framework makes comparisons of project straightforward, with each project nominally using the same evaluation categories, and similar processes for calculating metrics. While this is beneficial from the point of view of a federal funding agency responsible for assessing dozens of disparate projects across the country, these benefits are not necessarily realized by the local transit agencies. The standardized evaluation process also makes it straightforward to compare one project (or phase) to another.

There are also several downsides to maintaining a universal AA / MAE process. By virtue of being a one-size-fits-all process, the key FTA evaluation criteria, particularly the cost-effectiveness measure, function as the bottom line. In reality, however, goals and objectives vary from project to project depending on the specific interests and issues of various cities and agencies. During the 1990s and 2000s, the cost-effectiveness measure was framed as "cost per new rider," but since that failed to account for benefits to existing riders, a more complicated process was developed to take into account travel time savings across the network. This became so cumbersome to measure that only a few very large projects, such as the Los Angeles Purple Line, bothered to complete the travel time savings modelling. Agencies and the FTA were also unhappy with the degree to which they were beholden to the consulting community to complete this modeling. In the 2000s, the 'Small Starts' / 'Very Small Starts' process was started, enabling agencies to bypass detailed modelling for the sake of smaller capital projects. Most projects now use that simpler AA process.

Ultimately, the rigidity of the evaluation process and the FTA's focus on the cost-effectiveness number has led to a tendency for agencies to shape projects around the evaluation criteria rather than what makes sense from a transportation and community benefit standpoint. The process also causes agencies to think of their systems as a series of individual corridors rather than as a network, as there is no provision for testing the combined benefits of multiple improved transit lines in a single system.

While TransLink (like all Canadian transit agencies) is not beholden to the FTA's AA evaluation process, it is likely that use of any standardized evaluation process will encounter similar challenges over time.

Figure 4-7: New Starts and Core Capacity Process



LESSONS LEARNT AND IMPLICATIONS

- Dividing the project into several phases supports staged funding and enables the project to maintain momentum even when sections may be stalled owing to opposition or other issues.
- A standardized approach to evaluation supports ready comparison between projects and is useful for funding decision-makers but restricts the ability to respond to and assess the unique features and benefits associated with a particular transit corridor.
- Assessment should take into account new riders as well as benefits to existing riders resulting from rapid transit.
- Transit projects should be conceived as a network, with provision for testing of the combined benefits of multiple improved transit lines in a single system.

4.5 KEY FINDINGS FROM OTHER JURISDICTIONS AND PROJECTS

This section details a list of key findings from other jurisdictions and projects not highlighted in the case studies provided above. Some findings relate to rail-based rapid transit service in particular; others relate to transit services and/or major infrastructure capital projects generally.

4.5.1 Alignment as Visual and Physical Barrier

At-grade transit alignments have the potential to disrupt traffic operations and make it difficult for pedestrians and traffic to cross to the far side of the alignment. This can discourage use of active transportation modes and make the environment feel less hospitable to users. However, at-grade transit alignments can also provide improved transit accessibility and disruption to traffic can be minimized through the use of coordinated transit signal priority. Signal priority aims to address movement along the corridor but does not address the turn movement bans that are required due to space constraints and the inability to create left turn bays that are required to protect vehicles turning across rail tracks. Consideration must also be given to whether an alignment should operate in roadway medians or side right-of-way.

Above-grade transit alignments have reduced impact on traffic operations and roadway access, but in some cases will still discourage active transportation. Above grade alignments can have similar implications on turning movements at intersections as the alignment will likely not be able to run down the side of the corridor. This will impact site distances and would have the similar challenges to at grade operations. An above grade alignment may also create visual barriers, obstructing sight-lines / views and negatively effecting the public realm.

4.5.2 Take Advantage of Existing Alignments or Other Rail / Hydro Corridors

Existing unused or underused transit alignments, as well as other rail or hydro corridors, provide opportunities to build new at- or above-grade transit alignments with minimal land expropriation and community disturbance. However, these are limited in the corridor from Arbutus to UBC.

4.5.3 Continuity of Technology (Mode) and Ease of Transfers

Continuity of technology or mode when extending transit service along an existing rapid transit corridor enables passengers to travel transfer-free along the entire length of the extended service. Switching technologies when extending a service requires passengers to transfer, imposing a transfer time penalty, which is particularly noticeable and negatively perceived by passengers.

Ensuring easy transfers between services and transit modes is critical. Extension of a rail service typically results in a redesign of local (feeder) bus routes connecting to the extended rail service. Transferring from feeder buses to the new rail service should be as painless as possible and requires a careful redesign of the bus feeder network.

It can be challenging to model ridership on an extended rail line before redesigning the bus feeder network which will funnel passengers to the new line extension. However, in the case of the Broadway Extension the well-established network of feeder bus services to the existing B-Line Express service provides a sound basis for feeder bus ridership estimates.

4.5.4 Success Factors Identified in Other Major Transit Capital Projects

- Minimizing time to construct the new facility.
- Focus on improving travel speed and reliability for passengers, which will ultimately drive ridership gains.
- Cost effectiveness considerations should take into account efficient operation which is often more important than minimizing initial capital costs. Efficient service will generate ridership and reduce net operating costs.
- Matching capacity of a new service to current and future demand. Building heavy rail (e.g. West Coast Express) is not required along a corridor projected to have fewer than 30,000 daily riders for the next 20 years. Similarly, building a BRT line to meet today’s demand will be more expensive in the long term if the BRT needs to be replaced with an LRT in the near future due to demand growth.
- Inducing significant reductions in vehicle kilometres travelled (VKTs) will reduce traffic congestion and auto operating costs and improve environmental performance.
- Providing access to employment and other key activity nodes which are likely to be major trip generators in the short and long term.

4.5.5 Risk Factors Identified in Other Major Transit Capital Projects

- Competitive procurement process, particularly for extensions to existing SkyTrain transit lines as incumbent teams may be perceived to having an unfair advantage.
- Heritage and archaeology sites within proposed alignments. These sites can impact project schedules and budgets significantly and can prove difficult to estimate mitigation strategies.
- Political election cycles, which can lead to changes, delays, or cancellation of major infrastructure projects.
- Not-in-my-backyard / in-my-backyard activism, which can disrupt major transit projects for the wrong reasons.
- Technology senescence – use of niche or outdated technology which can become difficult and expensive to operate and maintain and must ultimately be replaced.
- Reliance on tax-increment financing – expectations of future tax revenue due to increased development along a new or upgraded transit corridor rely heavily on assumed interest of private developers, which may not materialize in the short (or long) term.

5. BENCHMARKING SURFACE RUNNING LRT

Light rail operating speeds averaging 29 km/h on the Broadway corridor were developed for the LRT 1 and Combo 1 alternatives during the Phase 2 Evaluation. To assess the feasibility of this speed, a benchmarking study of North American and international LRT systems operating at-grade, but in designated lanes separated from other traffic, was undertaken. Headways, operating times, average operating speeds, transit unit, and line capacities assumed in the Phase 2 Evaluation were compared and validated against six LRT projects across North America and internationally.

5.1 BENCHMARKS FOR HEADWAY, SPEED & CAPACITY

An examination of transit signal priority (TSP) algorithms used in Vancouver and benchmark cities, as well as a review of the current TransLink service on the Broadway corridor, was undertaken. A TSP feasibility analysis was conducted for the benchmark and Phase 2 LRT systems in order to determine dependencies for minimum compatible headways, as well as high-level (rule-of-thumb) estimates for TSP effectiveness and viability along the Broadway corridor. Jurisdictions considered included Toronto, Boston, Portland, Karlsruhe (Germany), Sydney (Australia), and Zurich (Switzerland) which operate comparable systems to the options considered in the Phase 2 report. Data from these benchmark systems were compared with the assumptions in the Phase 2 Evaluation report.

5.1.1 Headway

The combined headway for Routes 9, 14, and 99 B-Line, where they operate in parallel along the Broadway corridor, is currently 1.6 minutes (a combined frequency of 38 transit units per hour). The Phase 2 Report describes the shortest possible headway on Broadway as being 2 minutes for an LRT[12]. Operating with this headway would increase LRT capacity to 14,400 passengers per hour. Attempting to achieve a 2-minute headway in an at-grade environment, on a busy corridor and with manual train control would be ambitious and would almost certainly result in frequent vehicle stoppages. Automatic train control (ATC) operating in a grade separated environment would be better suited to meet such a short headway; however, ATC technology in an at-grade environment is currently only in preliminary testing stages in a handful of locations globally. Headways as they relate to transit signal priority are examined in *Section 5.1.7.*

5.1.2 Capacity

The transit unit capacity for the LRT 1 option is noticeably higher than peers. However, this is not considered to be an unreasonable estimate. Line capacity (passengers per hour) is a simple function of transit unit headway and capacity. The Phase 2 Report describes transit units of two cars coupled together, each with a capacity of 240 passengers, for a total transit unit capacity of 480 passengers. There is no reason to doubt this transit unit capacity could be achieved with adequate track and platform design. Further, a peak headway of 4 minutes is considered feasible. The resulting line capacity of 7,200 passengers per hour is thus considered achievable if supported by appropriate transit units, tracks, and station design. It is worth noting that this volume is not observed in any of the benchmark systems as those that carry this many people tend to be fully grade-separated. Capacity above this could be possible with higher frequency operation; this would likely result in slower travel times negating some of the benefits of LRT over the B-Line.

[12] *Steer Davies Gleave, 2012. UBC Line Rapid Transit Study - Phase 2 Evaluation Report, p. 36.*

Similarly, the Phase 2 Report RRT option line capacity of 13,000 passengers per hour (with a headway of 3 minutes) seems reasonable given the configuration and operating characteristics of existing Expo, Millennium and Canada Lines.

5.1.3 LRT Speed Benchmarks

Table 5-1 presents data from the Phase 2 Evaluation Report as well as examples of the existing service on the Broadway corridor and the existing Millennium Line as a (grade-separated) point of reference.

Table 5-1: Comparative Data for Transit Systems

	City / Agency	Route	Peak Headway (min)	Transit Unit Capacity (PAX / TU)	Line Capacity (PAX / h)	Round-Trip Operating Time in Peak (min)	Round-Trip Route Distance (km)	Average Speed (km / h)
Phase 2 Report	TransLink	UBC Line RRT	3	650	13,000	37	26	43
	TransLink	UBC Line LRT 1	4	480	7,200	56	27	29
Existing TransLink Services	TransLink	Route 9	5	77	924	126	33	16
	TransLink	Route 14	10	77	462	141	36	15
	TransLink	99 B-Line*	3	119	2,380	92	28	18
	TransLink	Millennium Line	3.5	260	4,457	72	62	52
	TransLink	Broadway corridor	1.6	77 / 119	3,766	-	-	-
Benchmark Systems[13]	Toronto / TTC	512 St. Clair streetcar	3	251	5,020	59	13	13
	Toronto / TTC	Eglinton Crosstown** (grade separated)	3	251	5,020	39	18	28
	Toronto / TTC	Eglinton Crosstown** (at grade with separated travel lane)	3	251	5,020	38	14	22
	Boston / MBTA	Green Line B Branch	6	269	2,690	66	20	18
	Portland / TriMet	MAX Yellow Line	15	372	1,488	71	22	19
	Sydney (AUS) / Transdev	Dulwich Hill Line 1	8	272	2,040	73	26	21
	Karlsruhe (GER) / VBK	Tram Line 1	10	244	1,464	67	20	18
	Zurich (SWI) / ZVV	Route 6	7	116	994	42	10	14

[13] *All the US and international LRT systems cited operate at-grade within a separated travel lane.*

**Note that west of Arbutus the 99 B-Line service runs faster and more reliably than east of Arbutus where the density of intersections and land use is higher.*
***Eglinton Crosstown LRT opening 2021; western portion is grade-separated, eastern portion will operate at-grade*

The benchmark LRT systems have a combined average operating speed of 19 km/h, with the fastest being the Dulwich Hill Line at 21 km/h (slightly slower than the forecast 22 km/h for the EC LRT), and the slowest being 13 km/h (512 St. Clair streetcar). By comparison, the estimated operating speed for LRT 1 presented in the Phase 2 Report appears optimistic at 29 km/h. Only the EC LRT – which will operate in a grade separated environment – is comparable.

Ultimately, operating speed and other characteristics must be determined through detailed service operational analysis, including modelling to assess transit unit acceleration and deceleration factors; maximum operating speed; stop spacing; vehicle loading and unloading characteristics which affect stop dwell times; traffic signal timing at each intersection; TSP operation; etc. However, based on the benchmarking review, rules of thumb, and order-of-magnitude analysis, a more realistic average operating speed for LRT 1 would be in the neighbourhood of 20-25 km/h.

5.1.4 Review of Transit Signal Priority

The effectiveness and appropriateness of TSP is dependent on the extent of its implementation, the scope of its operating rules, and the interplay between several characteristics of transit operation. As such, the success of TSP tends to be situation-specific, and it can be challenging to predict the success of TSP in a given corridor based on successes in other corridors, jurisdictions, or service types. Factors that affect the feasibility and success of TSP include:

- The number of intersections to be equipped with TSP
- Rules upon which TSP service is provided (passive vs. active TSP, conditional vs. unconditional)
- The algorithms used to increase green light time (‘green extension’), reduce red light time (‘red truncation’), insert traffic phases (‘phase insertion’), and/or reorder or skip traffic phases (‘phase rotation’ or ‘ phase skipping’)
- Service headway (frequency)
- Service right-of-way (ROW C, i.e. mixed traffic vs. ROW B, i.e. dedicated lanes)
- Passenger loading (nearside vs. far side stops, average dwell time per stop)
- Congestion along transit corridor
- Vehicle and pedestrian volumes at cross-streets
- Width of the corridor for minimum pedestrian crossing times
- Traffic signal timing
- Other transit services operating in parallel along the corridor
- Other transit services operating along cross-streets
- Other factors

Key considerations in determining how appropriate and effective TSP will be for a given service are discussed below. Considerations are presented in the context of case studies from Vancouver and other cities around the world.

5.1.5 LRT Speeds

The Phase 2 Report operating plan indicates that the LRT 1 option would operate on a 4-minute headway with ‘full signal priority.’[14] However, the type of priority given to transit is not clearly defined within the operating plan. It should be noted that transit units are unlikely to receive signal pre-emption and would instead rely on passive TSP and conditional (active) TSP. While TSP can be provided to transit lines operating with this level of frequency (i.e. 4-minute headway, or 15 transit units per hour), the effectiveness of the TSP is by no means certain.

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[14] *Steer Davies Gleave, 2012. UBC Line Rapid Transit Study - Phase 2 Evaluation Report, p. 90.*

Total expected operating time for the proposed 13-kilometre LRT 1 option is 26.5 minutes, assuming priority at 13 minor intersections and no priority at nine major intersections (i.e. no dwell time at minor intersections but dwell times at all major intersections).[15] 'Best' and 'worst' case scenarios were also tested, with the 'best case' (i.e. no stopping and waiting at any intersection) taking 25.1 minutes, and the 'worse case' (i.e. stopping and waiting at all 22 intersections) taking 31.4 minutes. The difference between the 'best' and 'worst' case scenarios, 6.3 minutes, indicates an average of 17 seconds of delay per intersection.

The Phase 2 Report states that time savings for the LRT 1 option were estimated at 3-4 minutes per trip (compared to operating at a 2-minute headway with reduced signal priority),[16] which indicates savings of 15-18 seconds for each of the 13 minor intersections described along the Broadway corridor (since no TSP would be provided at major intersections). This appears to indicate that virtually all stopping time at minor intersections could be eliminated by providing TSP, which is not likely achievable.

Based on industry experience, time savings of approximately 0.5 – 1 second per transit unit per TSP-equipped intersection would be expected for vehicles operating in ROW C, with somewhat higher time savings anticipated for ROW B operation. However, time savings will depend on the agency, the rules governing TSP operation, traffic conditions, etc.

Given the complexity of installing a light rail transit system on a busy corridor and the interaction with other transportation modes, the average vehicle operating speed assumed for the LRT 1 and Combo 1 alternatives in the Phase 2 Report was deemed to be too optimistic (29 km/h) for the Broadway corridor. It was therefore concluded that an operating speed of 25 kilometres per hour, comparable to other LRT projects with similar land use and traffic activity, would be most appropriate to model the two light rail options.

5.1.6 Speed Benchmarks

Common practice in most European TSP systems that employ active conditional priority with nearside stop locations is that priority may not be requested while doors are open and passengers are boarding / alighting. This prevents a priority request while a bus is not in motion, thus ensuring that green time is not wasted.[17]

In Zurich, a dynamic traffic signal control system was developed using the intersection geometry and live traffic data, rather than a perpetually repeating cycle at each intersection.[18] This allows green time to be used most effectively, adding only 5-8 seconds on average to green lights, and limiting wasted green time through reducing frequency of strings of successive green lights. Ultimately, this system allows green waves to be oriented around transit and transit priority measures, decreasing the frequency of extended or early green events, especially those that are either unnecessary or unachievable (i.e. the vehicle is unable to cross the intersection during the current cycle, regardless of TSP activation).

In Melbourne, Australia, a number of case studies were undertaken in order to empirically assess the performance of both signal and space priority. TSP was equipped at 25% of case study intersections, while space priority (i.e. dedicated right-of-way) was provided along 61% of tracks. The result of this larger study was that space priority measures were found to reduce run times by an average of 1.6%, while signal priority measures reduced run times by an average of

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[15] Ibid., Appendix E, p. 8.
[16] Ibid., p. 146.
[17] Currie, Graham. 2006. "Assessing Australian Transit Signal Priority Against World's Best Practice." Research into Practice: 22nd ARRB Conference. AARB Group Ltd.
[18] Ibid.

0.5%.[19] Operating time variability saw greater impacts, with reductions of 10.2% and 1.9% for space priority and signal priority respectively.[20]

In North American cities, bus signal priority is most commonly applied to systems that operate in mixed traffic on arterials with 4-6 total lanes. Few agencies in North America apply TSP for buses where the vehicles operate in ROW B. However, for LRT, TSP was applied almost exclusively to systems operating in ROW B, with the exception of streetcar lines in Toronto and Philadelphia, the majority of which operate in mixed traffic.[21]

In Sheffield, UK, the TSP system allows for the provision of compensatory green time during the following signal cycle for cross-street traffic, after a TSP call by a transit unit has been terminated. Compensatory time is reallocated from the transit unit's direction of travel to the cross-street, for a duration equivalent to the TSP extension / truncation, offsetting the request and returning signal coordination to its default state.[22] Similarly in Melbourne, compensatory green time is automatically provided for cross-streets following TSP activation. Melbourne differs from Sheffield in that there are offsets which appear as green extension or red truncation, as well as a clearance phase which allows transit units to call a "leading right turn" phase to clear traffic from its lane.[23]

With regards to emerging technologies in TSP, 'predictive' priority is being assessed and tested in simulations on various lines. A study on Salt Lake County, Utah's University LRT line priority presents the concept of predictive priority as a strategy that uses traditional TSP strategies in addition to peer-to-peer communications between intersections. This allows for priority requests to be called in advance and uses this in combination with network information to provide priority for LRT in advance of the vehicle's arrival at the intersection.[24] Ultimately, this variety of active TSP seeks to prepare intersections for approaching vehicles and give them priority without causing additional delays to vehicle or pedestrian traffic, while simultaneously maintaining signal coordination.

5.1.7 Technical Parameters of TSP

The following sub section provide a discussion of the technical features of TSP that have an impact on LRT operating speeds.

Transit Service Headway

A study of Vancouver's 98 B-Line on Granville St. in 2004 determined that TSP is most effective when vehicle headway is approximately 10 minutes, with effectiveness decreasing roughly linearly as headways deviate further from 10 minutes[25]. While not a rule, this timing acts as an important guideline for determining how often and through what methods TSP should be implemented under the operating conditions on a major arterial in Vancouver. *Figure 5-1* demonstrates the impact of TSP on bus travel times at various headways. Other factors identified by the report that increase the effectiveness of TSP are little to no turning volume hindering bus movement, far side bus stop location, and a slight-to-moderate volume to capacity (v / c) ratio. While instructional, this report is based on VISSIM micro-simulation for a bus operating in ROW C, therefore practical application may vary for ROW B LRT systems.

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[19] Currie, Graham, Kevin Chun Keong Goh, and Majid Sarvi. 2013. "An Analytical Approach to Measuring the Impacts of Transit Priority." TRB 92nd Annual Meeting Compendium of Papers. Transportation Research Board.

[20] Ibid.

[21] Smith, Harriet R, Brendon Hemily, and Miomir Ivanovic. 2005. Transit Signal Priority (TSP): A Planning and Implementation Handbook. Washington: US Department of Transportation.

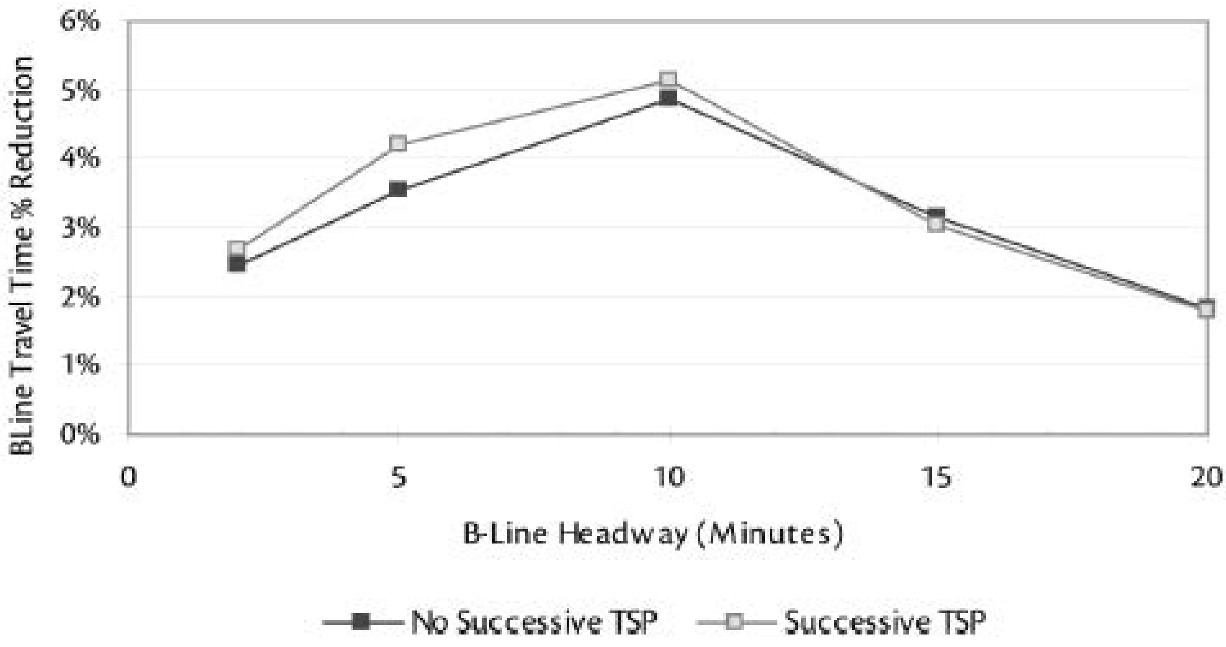
[22] Wikispaces. n.d. Improve Public Transport. Accessed March 2018. http: / / improve-public-transport.wikispaces.com / INTRO_TSP.

[23] Currie, Graham, and Amer Shalaby. 2008. "Active Transit Signal Priority for Streetcars: Experience in Melbourne, Australia, and Toronto, Canada."

[24] Zlatkovic, Milan, Peter Martin, and Aleksandar Stevanovic. 2011. "Predictive Priority for Light Rail Transit." Journal of the Transportation Research Board 168-178, p. 169

[25] Ngan, Vikki, Tarek Sayed, and Akmal Abdelfatah. 2004. "Impacts of Various Parameters on Transit Signal Priority Effectiveness." Journal of Public Transportation, pp. 71-93.

Figure 5-1: Bus Headway Impact (with TSP)



Frequency of Activation

Another important factor in determining the effectiveness of TSP is its frequency of activation. In Vancouver, when a multi-phased signalized intersection experiences a high frequency of TSP calls, (i.e. during 15-20% of cycles), a phase insertion strategy is generally recommended. This will allow for transit vehicles to maintain a reasonable level of priority, while minimizing the negative impact experienced by other vehicles, especially those at cross streets, by dynamically adjusting signal cycle phases. Overall, signal priority is granted for approximately 5% of cycles throughout the day in Vancouver[26].

In the United States, according to one examination of US transit agencies, a rule of thumb for signal controllers is that a new TSP request should not be granted if it is within 15 minutes of the previous request[27]. This allows time for the intersection to return to its normal signal cycle after having been disrupted by TSP, and to minimize the potential of a queue overflow on cross-streets. Similarly, the 98 B-Line study on Granville St noted that TSP calls are not responded to for two successive signal cycles to reduce adverse effects on cross-street traffic.

With these above factors in mind, the shortest possible headway for every transit unit to be able to take advantage of TSP is 2x the traffic signal cycle time. However, one must also consider that transit units travel in two directions along the Broadway corridor. As such, the bi-directional headway must be 2x the traffic signal cycle time, with the one-directional headway no less than 4x the traffic signal cycle time, in order for every transit unit to be able to request TSP activation.

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[26] *IBI Group and Translink. 2003. 98 B-Line Rapid Bus Transit Evaluation Study. Transport Canada.*
[27] *Han, Xu, Pengfei Li, Tony Z Qui, and Amy Kim. 2013. "Transit Signal Priority Impact Analysis and Evaluation in the City of Edmonton." TAC Conference and Exhibition - Transportation: Better-Faster-Safer. TAC / ATC, p. 3.*

Passive vs. Active

There are two primary types of TSP employed by signal systems: passive and active. Passive TSP refers to a system that has developed signal settings and phases in order to favour transit units and does not react to live traffic conditions. Instead, in its development, this system considers the operating characteristics of transit units. The typical result is that traffic is improved for all vehicles along the transit unit's route.

Conversely, active TSP involves a dynamic system that responds to requests from approaching transit units, where priority is given either conditionally or unconditionally. Techniques for active TSP typically involve green extension and/or red truncation. The maximum length of green extension is typically about 15 seconds in Vancouver, with an average of 6 seconds of extension provided, and is equally effective for most intersections in theory[28]. Red truncation effectiveness varies, with effectiveness decreasing at intersections with high cross-street pedestrian cycle minimums, as these cannot be shortened in order to ensure that pedestrians are always able to cross safely.

Cities / transit agencies are able to employ a mix of both passive and active techniques in order to try and realize a more effective priority system for transit. In Toronto, for example, both active and passive techniques are used. The EC LRT will rely primarily on passive TSP due to its short headway (3 minutes, i.e. a bi-directional headway of 1.5 minutes) being incongruous with the traffic signal cycle time of 2 minutes.

Conditional vs. Unconditional

Systems that employ active TSP for transit units can be described as giving either conditional or unconditional priority. Unconditional priority means that priority is always given to transit units, independent of other factors. Systems employing active, unconditional TSP may face issues related to reliability, headway variability, bunching, and congestion on cross streets due to altered traffic signal cycles.

In Melbourne, Australia, TSP is provided at all 600 signalized intersections and all signalized pedestrian crossings[29]. TSP employed on this network is conditional, loosely based on schedule adherence, and the application of priority is through green extension or red truncation. Green extension in this case is limited to a maximum of 20% of signal cycle time[30]. Similarly, Portland, Oregon's TriMet employs a conditional TSP for its MAX Yellow Line (as well as all other frequent service lines)[31] based on schedule adherence, resulting in green extensions[32].

Therefore, the shortest headway compatible with TSP is dependent upon a number of factors including: traffic conditions, cycle timings, dwell time reliability, conditional or unconditional permission, interactions with other modes and time of day. The shortest time benchmarked for an LRT system in ROW B employing TSP is 3 minutes, in Toronto for both the 512 St. Clair and EC LRT, though it should be noted that the majority of TSP benefit expected to be achieved by the EC LRT is due to passive TSP, while the 512 benefits from both active and passive TSP.

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[28] IBI Group and Translink. 2003. 98 B-Line Rapid Bus Transit Evaluation Study.
[29] Currie, Graham, and Amer Shalaby. 2008. "Active Transit Signal Priority for Streetcars: Experience in Melbourne, Australia, and Toronto, Canada. "Transportation Research Record-Series 41-49, p.42.
[30] Ibid.
[31] Retrieved at: https: / / trimet.org / schedules / frequentservice.htm
[32] PB Farradyne and Battelle. 2001. Tri-Met 5-Year Intelligent Transportation System Plan, p. 5.

6. REVIEW DELIVERABILITY OF LRT SPEED AND CAPACITY

This section provides a review of the potential operating plans for LRT service between the Main St/Science World Skytrain station and the UBC campus. Two LRT alignments were considered: a ‘full’ alignment, from Main St. / Science World to UBC (Combo 1), and a ‘partial’ alignment, from Arbutus St to UBC (Modified LRT 1). An analysis of the following key parameters was undertaken:

- Proposed and maximum LRT vehicle and train length, capacity, speed, frequency, on a stop-by-stop basis
- Travel demand model ridership outputs (westbound, peak-hour) to determine if the proposed and maximum LRT capacity is sufficient to accommodate forecast ridership.

6.1 METHODOLOGY, ASSUMPTIONS & LIMITATIONS

A high-level simulation model to estimate LRT run times based on assumed train acceleration and deceleration speeds, stochastic modelling of dwell times at intersections and stations, and stochastic modelling of likelihood of dwelling at intersections and stations was built. Each intersection was classified as ‘major’ or ‘minor’, with major intersections defined as those with traffic signals in both directions (i.e. N/S and E/W), and minor intersections defined as those with traffic signals in a single direction (e.g. E/W only) or unsignalized. Intersections with ‘right-in, right-out’ movements only, four-way stops, and those assumed closed under the new alignment were not considered as they are not anticipated to interfere with the operations of the LRT vehicles (for instance, when the LRT is operating in its own right-of-way on the Arbutus Greenway). Intersections were also identified as being within commercial, residential, or mixed-use corridors, with commercial and mixed-use districts having higher stop probabilities than residential corridors.

Stations were also classified as ‘major’ and ‘minor’. Major stations were defined as those with more than 300 passenger boardings plus alightings per hour in the westbound direction, since only westbound travel demand forecasts were assessed; minor stations were defined as those with fewer than 300 passenger boardings plus alightings per hour westbound. Vehicles were assumed to be 40m vehicles joined in two-vehicle consists, for a total train length of 80m, as per proposed platform lengths. Acceleration and deceleration rates were assumed to be 0.866m/s^2 and 1.0m/s^2 respectively, as per the City of Edmonton Valley Line LRT Technical Design Guidelines[33] which provides the average acceleration rate for a 40m LRV, and the Steer Davies Gleave (SDG) Phase Two Evaluation Report which provided the deceleration rate.

Distances between intersections, and between intersections and stations were calculated using the SDG UBC Line Rapid Transit Study Design Workbook 3 (2012) and the Google Maps measurement tool. Distances were measured from the front of the station, and where a single station was split at an intersection, the westbound station was used. Intersection distances were measured from the middle of the intersection.

[33] *https://www.edmonton.ca/documents/ValleyLineLRTTechnicalDesignGuidelinesAugust2012.pdf*

The model was run 50 times for each of several sets of parameters to obtain average figures of speed and travel time, with dwell times selected stochastically within specified ranges using uniform probability distributions to simulate the variability observed in real-world applications. Model runs were completed with the parameters presented in *Table 6-1*.

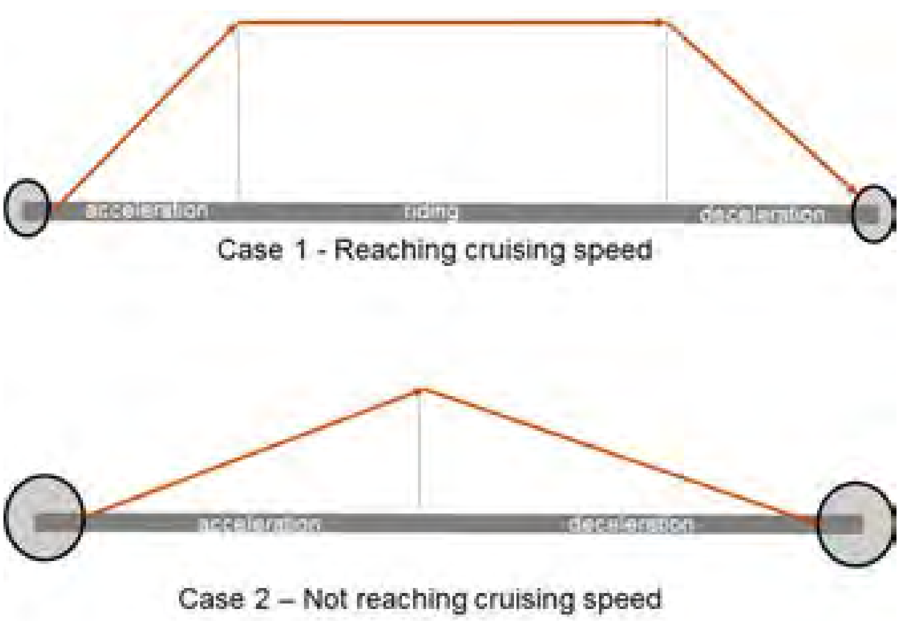
Table 6-1: Speed and Stop Probability Parameters

Max Speed – East of Blanca St (km/h)	Max Speed – West of Blanca St* (km/h)	Stop Probability
50	70	Stochastic (defined below)
60	70	Stochastic (defined below)
50	70	All stops (stations + intersections)
60	70	All stops (stations + intersections)

**Note: Between Blanca St and Wesbrook Mall where the corridor is generally surrounded by green space and limited intersections. Note that max LRT speeds were assumed to exceed the posted speed limit for adjacent traffic (50 km/h), which may not be achievable.*

The model also captured how many times the LRT vehicle would reach cruising speeds with stochastic stop probability and with 100% stop probability at all intersections and stations. Summary and results of these model runs are in *Table 6-4* and *Table 6-5* in the next section, and detailed parameters with regards to stop and station distances, classification, and land use are described in *Table 6-3*.

Figure 6-1: LRT Vehicle Movement Speed Profiles



Dwell times at intersections and stations were modelled using the following criteria. For major intersections, dwell times were assumed to be between 0-30 seconds at a 33% stop probability in residential areas, and 50% for commercial / mixed-use areas to recognize a higher level of pedestrian and cross traffic activity. For minor intersections, dwell times were assumed to be between 0-20 seconds at a stop probability of 25% in residential areas, and 50% in commercial/mixed-use areas. All other intersections assumed a stop probability of 0% and no dwell time. Major stations were assigned dwell times of 30-60 seconds and a stop probability of 100%. Minor stations were assigned dwell times of 15-30 seconds and a stop probability of 100%. For terminus stations (Arbutus, Main St./Science World, and UBC), we assumed maximum dwell time (60 seconds) at 100% stop probability. *Table 6-2* defines the stop probabilities and dwell times for the various intersections and station types.

Table 6-2: Intersection and Station Stop Probability and Dwell Times

Intersection / Station Type	Description	Stop Probability	Dwell Time (s)
Major Intersection	Signalized in both directions	33% (residential areas) 50% (commercial areas)	0 – 30
Minor Intersection	Signalized in primary direction, stop sign in secondary	25% (residential areas) 50% (commercial areas)	0 – 20
Other Intersections	Non-signalized intersection, stop sign in secondary direction	0%	0
Major Station	Above 300 pphpd boarding or alighting	100%	30 – 60
Minor Station	Below 300 pphpd boarding and alighting	100%	15 – 30

Table 6-3 below shows a list of intersections and stations with classification (major/minor); distance from the previous intersection / station; and land use classification (residential, commercial, or mixed-use).

Table 6-3: Intersection and Stop Classifications and Distances

Station / Intersection Name	Classification (Major, Minor)	Distance from Previous Station / Intersection (m)	Land Use Classification
Main Street-Science World	Major Station	0	Commercial
Terminal – Station	Major Intersection	33	Commercial
Central – Station	Major Intersection	510	Commercial
E 1st – Quebec	Major Intersection	145	Commercial
E/W 1st – Ontario	Major Intersection	143	Commercial
W 1st – Manitoba	Major Intersection	150	Commercial
Columbia	Minor Station	150	Commercial
W 1st – Cook	Minor Intersection	50	Commercial
Cambie	Major Station	11	Commercial
W 2nd / 6th – Ash	Major Intersection	809	Mixed
W 6th – Moberly	Major Intersection	230	Residential
W 6th / Lamey's Mill – Spruce	Minor Intersection	600	Residential
W 6th / Lamey's Mill – Alder Crossing	Major Intersection	240	Residential
W 3rd – Anderson	Major Intersection	530	Commercial
Granville	Major Station	150	Commercial
W 4th – Fir	Minor Intersection	40	Commercial
W 5th – Fir	Minor Intersection	120	Mixed

Station / Intersection Name	Classification (Major, Minor)	Distance from Previous Station / Intersection (m)	Land Use Classification
W 6th – Pine	Minor Intersection	200	Mixed
Burrard	Major Station	140	Mixed
W 6th – Burrard	Minor Intersection	40	Residential
W 6th – Cypress	Minor Intersection	170	Residential
W 6th – Maple	Minor Intersection	170	Residential
W 7th – Arbutus greenway	Minor Intersection	170	Residential
Arbutus	Major Station	150	Commercial
Broadway – Arbutus	Major Intersection	80	Commercial
Broadway – Yew	Major Intersection	180	Mixed
Broadway – Vine	Minor Intersection	170	Commercial
Broadway – Trafalgar	Minor Intersection	510	Commercial
Broadway – MacDonald	Major Intersection	250	Commercial
MacDonald	Major Station	110	Commercial
Broadway – Trutch	Minor Intersection	450	Commercial
Blenheim	Minor Station	130	Commercial
Broadway – Blenheim	Minor Intersection	10	Commercial
Broadway – Collingwood	Minor Intersection	290	Commercial
Alma	Minor Station	200	Commercial
Broadway – Alma	Major Intersection	70	Commercial
10th – Alma	Major Intersection	90	Commercial
10th – Highbury	Minor Intersection	140	Residential
10th – Camosun	Minor Intersection	670	Residential
10th – Trimble	Minor Intersection	660	Residential
10th – Sasamat	Minor Intersection	220	Residential
Sasamat	Minor Station	150	Residential
10th – Tolmie	Minor Intersection	70	Residential
10th/University – Blanca	Major Intersection	230	Residential
University – At St. Anselm's Church	Minor Intersection	1,070	Residential
University Boulevard	Minor Station	580	Residential
University – Toronto	Minor Intersection	30	Residential
University – Acadia	Minor Intersection	120	Residential
University – Allison	Minor Intersection	290	Residential
University – Western	Minor Intersection	130	Residential
University – Westbrook Mall	Major Intersection	110	Residential
UBC	Major Station	200	Residential

6.2 OPERATING MODEL OUTPUTS

Figure 6-2 illustrates the outputs from the LRT operating model demonstrating the variability in outputs with each model run. As shown, the run times vary from 25.7 to 32.1 minutes for the full corridor and from 14.9 to 19.7 minutes for the partial corridor based on the random seed for each run. *Table 6-4* and *Table 6-5* below show the results of the model runs for both partial and full corridor alignments, with respect to average speed, average number of instances trains are expected to reach cruising speed in a full one-way trip, average run time, and transit vehicles required at a given headway. Averages for speed and run time are split into best run and total average. Best run indicates the highest average speed reached in one simulation, while total average represents averages across 50 simulations. All parameters related to dwell times and stop probabilities were selected stochastically using a uniform distribution within the specified range for Model Runs 1 and 2, while Model Runs 3 and 4 had stochastic dwell times within the stated range, and 100% stop probability for all stations and intersections. Note that Model Runs 1 and 2 were used to determine the average operating speed and Model Runs 3 and 4 were stress tests to determine the low end of operating speeds. Based on the results of the stochastic model runs, an average operating speed of 25 km/h was deemed most appropriate for the LRT options to operate along the Broadway corridor. As the LRT alternatives would not realistically stop at every intersection, the 100% stop probability model runs were intended to be sensitivity tests to determine the minimum operating speed.

Figure 6-2: LRT Operations Model Outputs for Full and Partial Corridor Simulations

Table 6-4: LRT Operating Model Runs, Full Corridor (Combo 1 Alternative)

Model Run	Maximum Speed Possible (km/h)	Average Speed (km/h)		Average Run Time (min)		Average Times Reaching Cruise Speed		Vehicles Required at Given Headways[34]	
		Best Run	Total Average	Best Run	Total Average	Main Corridor[35]	UBC Corridor[36]	3 mins	4 mins
1. Stochastic, Slow	50 (70 in UBC)	26.6	24.2	27.4	30.1	8.7	2.4	55	41
2. Stochastic, Fast	60 (70 in UBC)	27	24.6	27.1	29.7	9.1	2.5	55	41
3. 100% Stop Probability, Slow	50 (70 in UBC)	18.5	17.7	39.5	41.1	0	0	78	56
4. 100% Stop Probability, Fast	60 (70 in UBC)	19.0	17.9	38.5	40.7	0	0	74	55

Table 6-5: LRT Operating Model Runs, Partial Corridor (Modified LRT 1 Alternative)

Model Run	Maximum Speed Possible (km/h)	Average Speed (km/h)		Average Run Time (min)		Average Times Reaching Cruise Speed		Vehicles Required at Given Headways[37]	
		Best Run	Total Average	Best Run	Total Average	Main Corridor[38]	UBC Corridor[39]	3 mins	4 mins
1. Stochastic, Slow	50 (70 in UBC)	30.3	25.9	14.6	17.1	3.7	2.4	32	25
2. Stochastic, Fast	60 (70 in UBC)	33.3	26.8	13.3	16.5	4.2	2.5	32	23
3. 100% Stop Probability, Slow	50 (70 in UBC)	20.2	18.9	21.9	23.3	0	0	44	32
4. 100% Stop Probability, Fast	60 (70 in UBC)	20.0	19.1	22.0	23.1	0	0	42	32

[34] *Includes a 15% ratio of spare vehicles.*
[35] *From Main Street-Science World stop to University – At St. Anselm's Church intersection.*
[36] *From University – At St. Anselm's Church to UBC stop.*
[37] *Includes a 15% ratio of spare vehicles.*
[38] *From Main Street-Science World stop to University – At St. Anselm's Church intersection.*
[39] *From University – At St. Anselm's Church to UBC stop.*

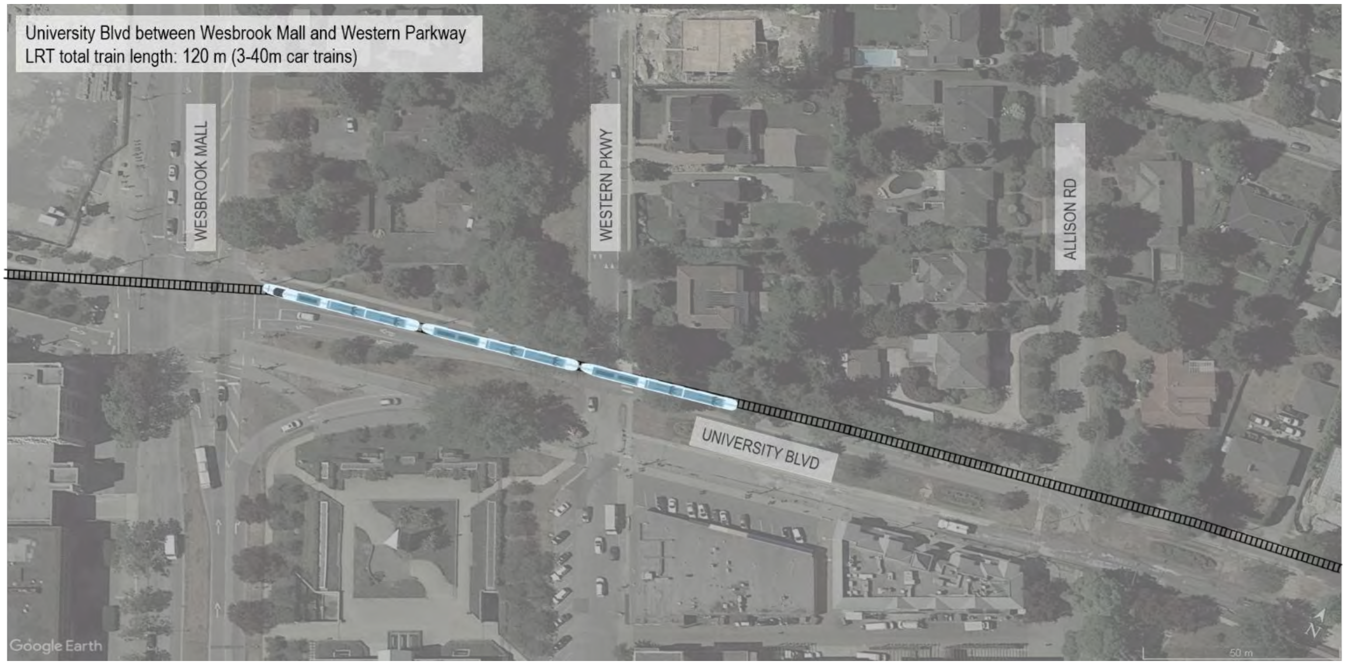
6.3 MAXIMUM CAPACITY

The maximum capacity of LRT is a function of achievable headways and train lengths. *Section 5* provides a thorough discussion of minimum achievable headways which, in the case of the Broadway corridor, is likely 4 minutes without running into operational challenges. At headways less than four minutes there is considerable risk with train bunching affecting overall reliability and travel times. In other words, a smaller headway would reduce passenger wait times for trains but would sacrifice line time and service reliability.

Train lengths could be extended to increase capacity, however, within Vancouver this will be challenging to achieve given standard block lengths. A two-car train is approximately 80m in length and provides a peak directional theoretical capacity of 7,200 pphpd at a headway of 4-minutes. Going to a four-car train would increase theoretical capacity to 14,400 at a headway of 4-minutes. *Figure 6-3* and *Figure 6-4* provide a diagram showing what a 3-car train at a length of 120m would look like at various segments of the study corridor. In both cases, a westbound train stopped at an intersection would block the upstream intersection creating significant challenges to other roadway users including cyclists and pedestrians. This situation would be further compromised with 4-car trains at 160m.

Figure 6-3: 3-Car Train Stopped at Macdonald St

Figure 6-4: 3-Car Train Stopped at Wesbrook Mall



7. LRT PROPERTY AND OMC REQUIREMENTS

This section discusses the property and operating and maintenance (OMC) yard requirements for LRT. For the property requirements along the corridor, the following were reviewed and analyzed:

- Right of way plan / property acquisition needs for the proposed LRT alignments
- High level classification of parcel by land use (commercial, residential, industrial)
- High level determination of fair market value for proposed right of way through examination of historic and current market sales data

For the OMC requirements, the following were reviewed and analyzed:

- Proposed LRT alignments and potentially suitable general locations for an LRT OMC, including a site access strategy for LRVs from proposed corridor
- Comparable LRT OMC facilities from other Canadian jurisdictions
- Approximate size of facility/property required to house an appropriate LRT OMC
- Class 5 assessment of probable costs for the facility and site development

7.1 RIGHT-OF-WAY ANALYSIS

For this review, the SDG Design Workbook, Google Maps, and BC Assessment[40] datasets were referenced to determine how many properties would be impacted by the proposed LRT alignment, as well as the estimated acquisition price of the properties. As most of the land parcels are occupied by existing structures, costs beyond property market value are expected and described below, however, this analysis does not incorporate any costs beyond purchase costs. Property values were estimated based on land and building prices, which may differ from the current and future market value of these properties. Where there was no direct estimate from an appraiser available to estimate acquisition costs, property values using the average price of similar developments in the surrounding area were estimated and normalized based on property area.

Total property acquisition costs are determined by a range. The low end of the range reflects the price of land acquisition only, and the higher end represents an order-of-magnitude cost for land acquisition plus extra costs, which include demolition, relocation, loss of business, disturbance, and injurious affection. As a rough approximation, the study team assumed that the costs beyond land acquisition are equal to the cost of land acquisition (i.e. total cost for acquiring and preparing sites for the LRT alignment is assumed to be roughly double the raw cost of land acquisition).

It is estimated that a total of 17 properties would be impacted by the proposed Combo 1 LRT alignment, at a total area of 19,830m^2. *Table 7-1* shows the total property area that would be impacted by the Combo 1 and Modified LRT 1 options, along with the estimated property acquisition costs.

[40] *https://www.bcassessment.ca/*

Table 7-1: Property Cost Matrix for Track Requirements

	Property Area (m^2)	Lower Bound Cost ($)
Combo 1	**19,830**	**302,124,742**
Modified LRT 1	**3,156**	**46,911,342**

7.2 MAINTENANCE FACILITY POTENTIAL FOOTPRINT

The study team assessed possible locations and cost for an OMC facility to support the full and partial LRT alignments. In addition, an option to coordinate vehicles with the proposed Arbutus Streetcar was considered in order to include undeveloped parcels in South Vancouver as potential OMC locations.

Based on the results of Task 1, the study team assumed a maximum fleet size of 80 vehicles (i.e. 40 trains) would be required to provide service for the 'full' LRT alignment. At 40m per vehicle, this indicates a maximum of approximately 3,200m (80 vehicles x 40m/vehicle) of storage track would be required, as well as associated maintenance and servicing space. The study team reviewed existing OMC facilities in Calgary and Edmonton with similar space requirements in order to determine potential lot size requirements and approximate size of required support spaces. Efficiencies in lot utilization provided a target minimum lot size for consideration. This process resulted in the identification of three potential areas for an OMC facility: South Vancouver, Northeast False Creek, and UBC and the University Endowment Lands. WSP also completed an order-of-magnitude cost assessment for a new LRT Operations and Maintenance Centre.

7.3 OMC LOCATION CONSIDERATIONS

The study team considered three locations for an OMC facility based on land availability, property costs, and the number of LRT vehicles required. The three areas considered for the facility were UBC/UEL, False Creek Flats, and South Vancouver. *Figure 7-1* shows potential site locations within the study area, while *Figure 7-2* to *Figure 7-4* show existing OMC facilities in Calgary and Edmonton with similar space requirements.

Figure 7-1: Potential OMC Locations

Locating the facility within the UBC/UEL area would be particularly challenging, given competing land-use interests and property values; False Creek Flats has at least one potentially suitable site, but also has high land values even for industrial lands given its proximity to downtown Vancouver; and South Vancouver has at least one potentially suitable site with lower land costs, though access costs would be considerable given its distance from the corridor. In all cases, a spur line would have to be constructed in order to provide access for LRT vehicles to the OMC facility.

Based on comparable OMCs assessed in Alberta, the study team estimated rough order-of-magnitude costs for an LRT OMC facility (ignoring property costs for the OMC, which have not been estimated) would be between $195,000,000 and $210,000,000, while space requirements would be in the 10–15 hectares range. For the purposes of this planning-level assessment, an additional $150 million is assumed for property acquisition and/or access costs of constructing a spur line to the facility.

Figure 7-2: Oliver Bowen LRT Maintenance Facility, Calgary. Approximately 13 hectares with 2,800 linear metres of storage track. Stores 108 x 26m Siemens LRT vehicles. Site has abundant amounts of unused space.

Figure 7-3: D.L. MacDonald Yard, Edmonton. Approximately 9 hectares with 1,560 linear metres of storage track. Stores 60 x 26m LRT vehicles. Turnaround tracks occupy large portions of the site.

Figure 7-4: Anderson LRT and Bus Garage, Calgary. Approximately 6 hectares (effective LRT area approximately 3.5 hectares). Stores approximately 54 x 26m LRT vehicles on 1,400 linear metres of track. Efficient site use with limited turnaround track functionality.

8. REVIEW OF RIDERSHIP AND COSTS

Updated ridership and cost estimates since the Phase 2 Evaluation were conducted utilizing latest available data and modelling tools. TransLink has released an updated Regional Transportation Model Phase 3 (RTM3) which has been significantly restructured and recalibrated. Many factors including escalation of labour and materials costs have led to increased construction costs for the Broadway Subway Project. This section provides a discussion of the approach and methodology to produce updated ridership and cost estimates, as well as the outcomes from this analysis.

8.1 UPDATED RIDERSHIP FORECASTS

8.1.1 Approach & Methodology

The RTM3 provides a significant update to the previous version of the regional model[41] that was used to prepare the Phase 2 Evaluation results. The RM-08 and RTM3 models are both enhancements of a previous 641 traffic zone regional transportation model. The RM-08 has 965 zones and additional zones were concentrated along the Gateway Program corridors such as Highway 1, South Fraser Perimeter Road, the Golden Ears and Pitt River Bridges. The RTM3 has 1,700 zones and the additional zones were distributed across the entire region, roughly proportional to where existing regional zones are located. The RTM3 provides much better zonal resolution in the rapid transit corridors over the primarily auto-oriented detailing found in the RM08. Updated land use from the 2011 and 2016 Census, travel behaviour from the 2011 Trip Diary and updated truck demand information from 2014 to represent the four primary freight market sectors were all included in the RTM3 update providing insight into present conditions in the region.

The RM-08 model only represented an AM peak hour condition and all travel parameters, trip purposes and demand profiles are specific to that single time period. The RTM3 models 24-hour regional travel demand and provides slices for analysis of the AM, midday, and PM peak hours at the network level. This provides much better ability to evaluate projects during the entire travel day rather than expanding a single peak hour to the entire day. It also provides insight into the off-peak response.

Five more travel purposes have been added to the RTM3 over those found in the RM-08 to represent those trips that predominantly occur outside of the AM peak. The key explanatory variables in the RTM3 have been updated to be household / employment based instead of population / employment based which is a departure from the previous regional model.

Significant enhancements to the representation of auto and transit travel have been made in the RTM3. Value of time segmentation has been added based on income segmentation and analysis of the 2011 Trip Diary so that different purposes respond to costs on the roadways differently. Some segmentation had been performed in the RM-08, but the values were asserted based on the initial value of time parameters + / - a sensitivity range. Travel time validation of the RTM3 found that the representation of auto delay was largely underestimated compared to observed in practice when using the formulation found in the RM-08 model. These volume delay curves were largely based on highway travel time validation and tended to underestimate the delays found in the urban context with closely spaced intersections. An updated set of assumptions was used in the RTM3 to correct this travel time bias. Transit services were also changed to

[41] *Termed Regional Model 2008, or RM-08.*

explicitly represent the capacity and stopping procedure which allows evaluation of service performance as demand exceeds capacity. Transit users were also segmented into bus and rail users and assigned separately as a distinct difference in travel behaviour for these users was seen in the trip diary data.

The under-representation of auto travel delay provided an implicit bias against transit services as they were competing with the auto mode running faster than observed in reality, even when significant enhancements to transit travel time were assumed in future rapid transit projects. The inability of previous modelling to represent transit capacity constraints also underestimated the benefits of providing transit services with sufficient capacity to serve the transit travel demand. The RTM3 now includes a congested and capacity constrained transit assignment which provides a more realistic representation of the transit network and transit demand.

8.1.2 Key Model Differences

Table 8-1 provides a summary of some of the key differences between the RM-08 and RTM3 models. Note that network assumptions in RTM3 are based on those available at the time when the model was released.

Table 8-1: Key Differences between RM-08 and RTM3 Models

	RM-08	RTM3
Regional Network Traffic Modelling		
1. Model Version	Regional Model 2008 (based on Gateway Subarea Model – GSAM)	Regional Transportation Model Phase 3 (with updates)
2. Road Networks	2011, 2015, 2021, 2031 Massey Tunnel and Pattullo Replacements + tolls	2011 – Base calibration 2015 – Port Mann, SFPR, Updated transit coding 2016 Post Evergreen Line road configuration 2030, 2045 future networks with Mayors' Vision projects
3. Transit Networks	Evergreen added to 2021 base condition Assume Broadway subway to Arbutus, Surrey LRT*	Evergreen added to 2016 base condition Assume Broadway subway to Arbutus, Surrey LRT* B-Line routes as identified in Phase 1 of Mayors' Vision 10-year plan
4. Major Projects (other than transit projects)	GMT Replacement (10 lane + toll) Pattullo Bridge Replacement (4 lane + toll)	216th Interchange 72nd Street Interchange Pattullo Bridge Replacement (4 lane + no toll)
5. Land use, population, employment	965 traffic zones, Growth Management Strategy land use, population and employment.	1,741 traffic zones, 2016 Draft land use (pop / emp / household) based on Census 2016 and BC stats employment forecasts
6. Time slices	AM 0730 - 0830 MD 1200 - 1300	AM 0730 - 0830 MD 1200 - 1300 PM 1630 - 1730
7. Base traffic volumes	2015-2016 for major regional facilities	Latest 2016 / 2017 counts at major crossings
8. Origin-destination patterns	OD from GSAM Model, Adjustments for TransLink's 2011 Trip Diary Additional Travel Time validation using 12 OD pairs	Calibrated to 2011 Trip Diary, Hwy 1 travel time validation

	RM-08	RTM3
9. Value of time per hour	In 2006 dollars: VoT (per hr): $9 (SOV); $20 (HOV); $40 (LGV); $50 (HGV); $9 Transit	SOV1 - $6.32; SOV2 - $10.34; SOV3 - $15.38; SOV4 - $18.18 HOV1 - $6.32; HOV2 - $10.34; HOV3 - $16.67 Transit - $12.24 LGV - $29.56; HGV- $41.96
10. Future population and employment growth	Growth Management Scenario	Regional Growth Strategy

**Note: The modelling work performed for this study assumes inclusion of the Surrey LRT in 2030 and 2045 based on information available at the time. Further analysis would be undertaken should a different technology be considered for the Surrey rapid transit project.*

The RTM3 is calibrated and validated to regional travel patterns and does not necessarily account for local travel conditions. As such, a validation of the study area corridor was carried out to ensure that traffic and transit volumes and travel times are well represented. This ensures that the model is replicating observed conditions providing a sound basis for developing the updated ridership forecasts.

8.1.3 Transit Boarding Penalty

One of the key model assumptions affecting transit ridership is the assumed transit boarding penalty; sometimes referred to as the transfer penalty. The previous transit boarding penalty perception factor of four had been in use since the pre-GSAM/RM-08 regional models as the transit assignment had not been changed significantly over time. The RTM3 introduced large changes to the transit assignment formulation including congestion effects, vehicle capacity constraints, journey-level assignment and explicit representation of fare boundaries which all changed the costs experienced in the transit network. In addition, new information from the Compass dataset showed a distinct bias towards more transfer activity in the model than observed in reality. As part of re-estimating the transit perception factors, the boarding factor was calculated in two ways independently:

- Increasing the value in the model assignment procedure until the Compass value of 1.65 boardings/trip was reached; and
- Re-estimating the regional mode share model based on updated compass information and transit costs from the new transit assignment technique.

Both of these methods yielded a value for the boarding perception factor of 10, which was subsequently added in the RTM3 model formulation. An estimate was made of the level of transfer overestimation in previous models, presented as the number of boardings/trip produced from each model as follows:

- GSAM/RM-08 (and earlier) – 1.8 boardings per transit trip
- RTM2 – 2.1 boardings per transit trip
- RTM3 – 1.65 boardings per transit trip
- Compass data – 1.65 boardings per transit trip

8.1.4 Model Validation

8.1.4.1 Travel Time Validation

With the widespread adoption of connected devices (smartphones, tablets, in-car GPS devices, etc.), crowd-sourced information on traffic travel time has become more readily accessible through sources such as Google Maps API. Because Google Maps bases their average travel time estimate on historical and real-time data, application of these travel time estimates has proved to be a valuable tool in validating the travel time estimates from the RTM3. To ensure that the RTM3 provides reliable travel times, modelled travel times were compared to Google Maps' best guess, pessimistic, and optimistic travel time estimates for the following corridors:

- 4th Avenue (EB/WB): Wesbrook Mall to Clark Drive
- 10th Avenue/Broadway (EB/WB): Wesbrook Mall to Boundary Road
- 16th Avenue (EB/WB): Wesbrook Mall to Fraser Street

Comparisons of corridor travel times for the three major corridors are presented in *Figure 8-1* and *Figure 8-2* for the AM and PM peak periods, along with detailed travel time plots found in *Appendix B*. In general, all the corridors fit reasonably well within the observed range.

Figure 8-1: Corridor Travel Times for AM Peak Period

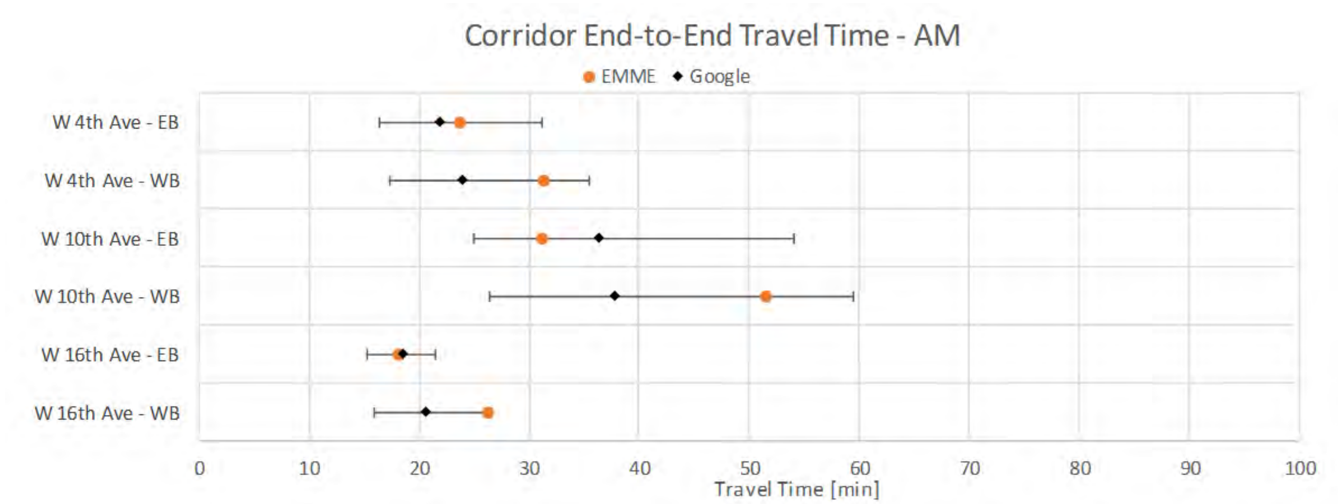
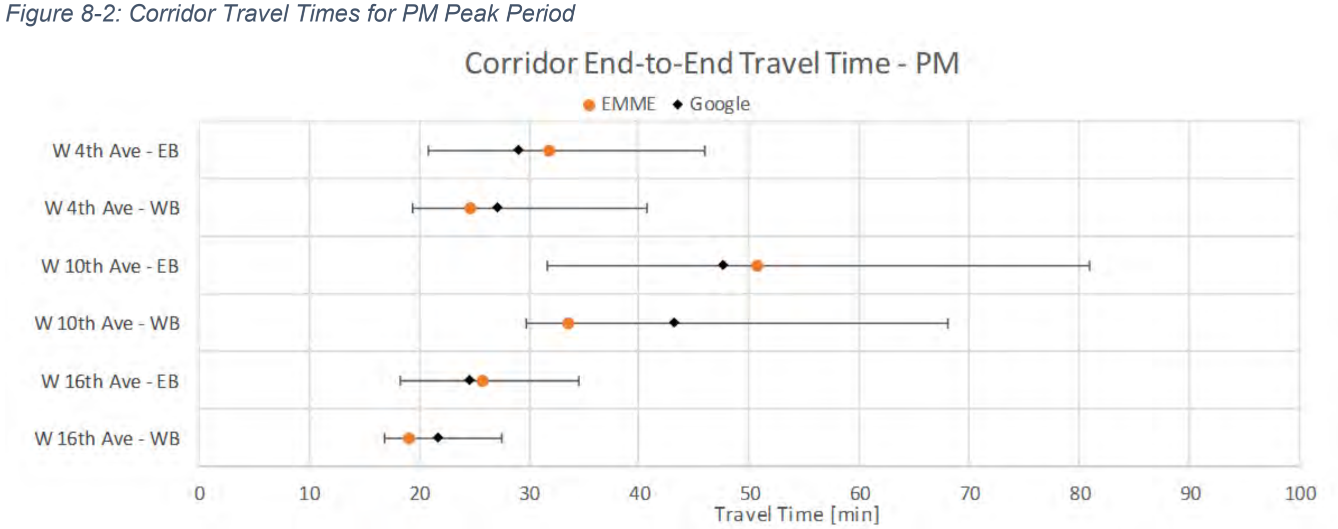


Figure 8-2: Corridor Travel Times for PM Peak Period



8.1.4.2 Volume Validation

Model volumes were compared to traffic count data provided by the City of Vancouver and UBC to determine how closely these match to observed traffic volumes within the study area. *Figure 8-3* presents a comparison of model (shown in red) versus count volumes (shown in blue) for the AM peak period and indicates that the RTM3 performs fairly well in matching traffic volumes on the corridors within the study area. However, the model significantly overestimates the amount of traffic occurring along Broadway between Arbutus Street and Blenheim Street. Model traffic volumes in the PM peak period showed similar results as seen in *Figure 8-4.*

Figure 8-3: Volume Validation Plot (AM)

Figure 8-4: Volume Validation Plot (PM)

8.1.4.3 Transit Validation

A comprehensive validation of the model's transit outputs was also undertaken to ensure that the model reflects corridor-specific transit travel patterns. The 2016 Base Scenario model transit volumes were compared against the observed segment volumes across the UBC screenline for the AM, MD, and PM peak hours. The model performed reasonably well in the peak flow directions but underestimated the transit demand for the off-peak as shown in *Table 8-2*. As a result, the model's time slicing factors were adjusted to better represent the observed time of day travel patterns specific to UBC. Review efforts also included adjusting the coding of transit routes as needed to properly reflect routing, stop locations, headways, and route run times. In general, transit run times were found to be within 20 percent of scheduled times, providing a level of confidence in using the model to generate ridership forecasts. It is important to recognize that although variation would be expected for observed run times, posted schedules were used as the basis for comparison due to lack of available information on actual transit operating times.

Table 8-2: UBC Screenline Transit Count Validation

		Model	Count	% Difference
AM	WB	8,230	6,760	22%
	EB	600	1,000	-40%
MD	WB	2,440	2,780	-12%
	EB	2,200	1,690	30%
PM	WB	890	1,680	-47%
	EB	6,250	5,980	5%

8.1.5 Rapid Transit Alternatives Considered

The three preferred alternatives from the Phase 2 study were coded into the RTM3 and then ran to produce updated ridership forecasts. Note that the LRT 1 alternative was modified, as shown in *Figure 8-6*, to include the BSP which has been committed to in the Mayors' Council 10-Year Vision. Additionally, the two LRT technology options were modelled with two fewer stop locations than what was previously assumed in the Phase 2 Evaluation to maintain consistency with the assumptions for the RRT option. The LRT has always been envisioned as an at-grade operation. A tunnelled LRT was not considered in order to provide a distinct technology alternative that is significantly less expensive to construct than the RRT alternative. Moreover, the B-Line (BAU) scenario was also altered to reflect the inclusion of the SkyTrain service to Arbutus. These adjustments allow for a consistent assumption between the preferred alternatives. *Figure 8-5* to *Figure 8-8* provide the rapid transit alignment and proposed station locations for the four transit options that were evaluated as part of this study. For the purposes of this stage of analysis, and for more direct comparability with Phase 2 findings, a second station at UBC has not been included in any alternative. Exploration of the costs and benefits of a second station at UBC should be explored in subsequent stages of alternative concept development and evaluation.

Figure 8-5: B-Line Alternative

Figure 8-6: Modified LRT 1 Alternative

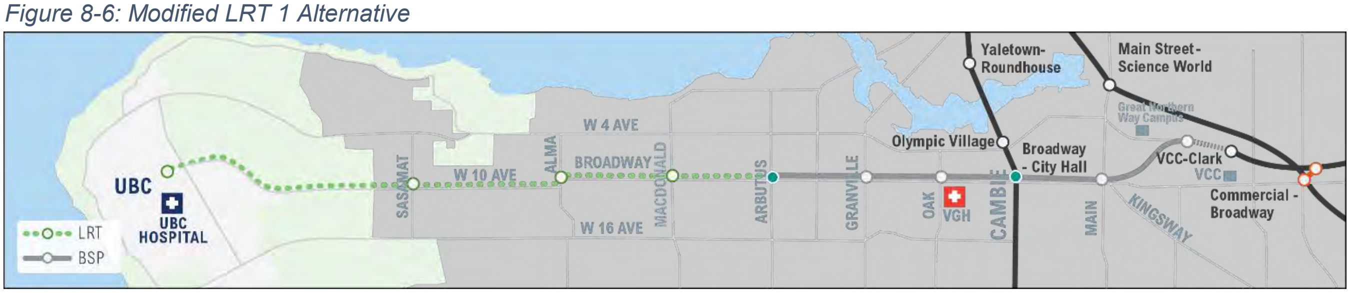


Figure 8-7: Combo 1 Alternative

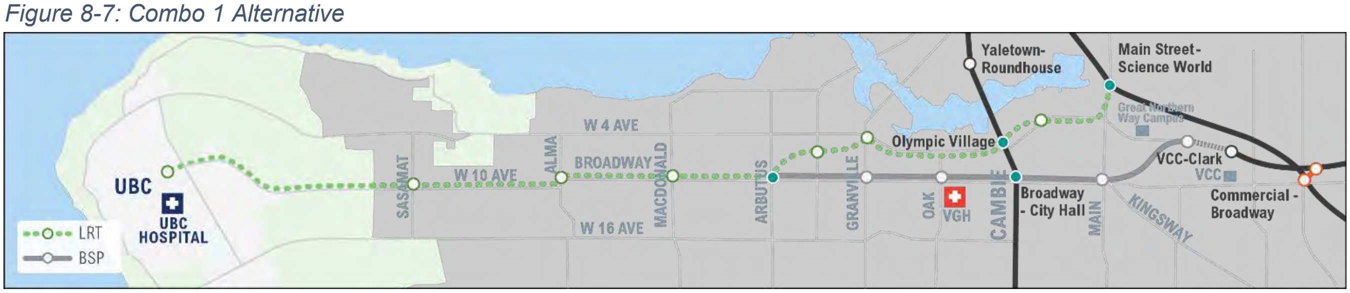
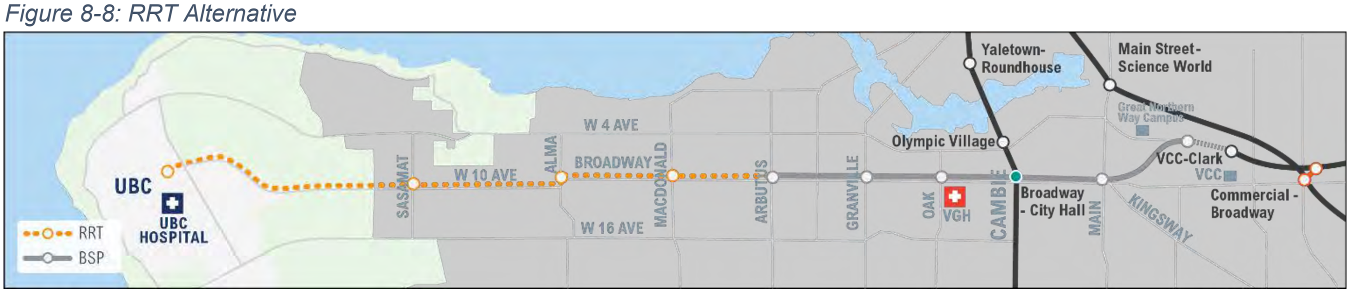


Figure 8-8: RRT Alternative



8.1.6 Land Use and Demographic Forecasts

Testing of the different transit alternatives (B-Line, Modified LRT 1, Combo 1, and RRT) to assess network performance conditions and transit ridership in 2030 and 2045 requires an understanding of regional land use forecasts as these play an instrumental role in estimating future trip-making. As such, demographic projections provided by Metro Vancouver were used as data inputs into the RTM3 to develop ridership and traffic forecasts for the planning horizon years.

Trip making in RTM3 is primarily driven from households, population, employment, and school enrollment. *Table 8-3* to *Table 8-6* provide a summary on the anticipated growth for the Metro Vancouver area, City of Vancouver, and the combined areas of UBC and UEL for these explanatory variables. As seen in *Table 8-3*, Metro Vancouver's land use forecast projects that population growth will see a 23 percent increase by 2030 and a 43% increase by 2045, when compared to population totals in 2016. UBC's population is expected to grow at a much faster rate than both the City and the entire Metro Vancouver region.

Table 8-3: Population Projections

Population			
Boundary	**2016**	**2030**	**2045**
Metro Vancouver	2,515,200	3,105,500 (23%)	3,590,600 (43%)
City of Vancouver	648,000	739,800 (14%)	795,800 (23%)
UBC	15,800	21,250 (34%)	26,150 (66%)

Employment totals (*Table 8-4*) show that job opportunities will experience the slowest growth leading up to 2030, compared to the population, household, and school enrollment projections. In the fifteen years which follow, it is anticipated that employment will continue to grow at similar rates. Note that students are treated separate from employment in the model so UBC students are not included in the figures below (see *Table 8-6*).

Table 8-4: Employment Projections

Employment			
Boundary	**2016**	**2030**	**2045**
Metro Vancouver	1,367,450	1,574,200 (15%)	1,779,450 (30%)
City of Vancouver	456,600	488,200 (7%)	514,900 (13%)
UBC	21,250	24,250 (14%)	27,200 (28%)

As seen in *Table 8-5*, within the region and City of Vancouver, households are expected to grow in a similar manner as population projections while the growth of households at UBC will outpace the population growth rate by 12 percent.

Table 8-5: Household Projections

Household			
Boundary	**2016**	**2030**	**2045**
Metro Vancouver	974,050	1,231,600 (26%)	1,442,550 (48%)
City of Vancouver	286,900	324,950 (13%)	352,100 (23%)
UBC	6,900	10,100 (46%)	12,200 (77%)

School enrollment is tracked as full-time equivalent (FTE) in the RTM3, which differs slightly from total enrollment numbers. It is projected that the number of FTE students attending UBC will increase from 47,400 in 2016 to 63,750 in 2030 and 74,050 in 2045, as shown in *Table 8-6*. School enrollment projections at UBC for 2030 were developed based on an assumed 2% annual growth rate, consistent with observed growth between 2008 and 2017, while 2045 projections were based on a 1% annual growth rate between 2030 and 2045. This is the primary variable that is driving ridership increases on the rapid transit alternatives to/from campus. Note that sensitivity testing was subsequently conducted to consider the effects of lower rates of enrollment growth at UBC on ridership demand (See *Section 11*).

Table 8-6: School Enrollment Projections

School Enrollment			
Boundary	**2016**	**2030**	**2045**
Metro Vancouver	192,350	230,600 (20%)	240,900 (25%)
City of Vancouver	58,150	63,250 (9%)	63,250 (9%)
UBC	47,400	63,750 (34%)	74,050 (56%)

8.1.7 Operating Assumptions

Operational characteristics used for the technical assessment of each of the shortlisted alternatives were kept largely consistent with the assumptions developed in the Phase 2 Evaluation. These operating assumptions are presented in *Table 8-7*. The Modified LRT 1 and Combo 1 alternatives were both modelled with two car trains operating at 4-minute headways in 2030 and 2045. The RRT option was modelled with four car trains for both horizon years. For 2030, the RRT operates at a 3.2-minute headway for the AM and PM peak periods and at a 6-minute headway for the midday. For 2045, the headways were reduced to 2.5 minutes for the AM and PM peak periods and 4 minutes for the midday. It should be noted that the assumptions made for the headway and capacity of the RRT option differ slightly from the Phase 2 Evaluation to maintain consistency with the operational characteristics assumed for the current service plan for the Broadway Subway Project. Further, LRT operating speeds were reduced from 29 km/h to 25 km/h based on the benchmark review of other LRT systems and results from the LRT operations model, as discussed in *Section 6*. Operating speeds were assumed to be consistent along the Broadway/10th Ave corridor. Since the majority of ridership is travelling through Arbutus to UBC, having different operating speed profiles between Arbutus and Blanca versus Blanca to UBC would not make a significant difference in ridership. Given that the RRT option could operate on its own exclusive guideway, it could operate at significantly higher vehicle speeds (42 km/h) compared to the other alternatives.

Table 8-7: Operational Characteristics Assumed for Alternatives

Alternatives	Route	Route Length (km)	Number of Stops	Headway (mins)	Operating Speed (km/h)	Theoretical Capacities (pphpd)*
B-Line + BSP	UBC – Arbutus	7.2	6	3	22	2,400
Modified LRT 1	UBC – Arbutus	7.1	5	4	25	7,200
Combo 1	UBC – Main Street-Science World	12.0	10	4	25	7,200
RRT	UBC – Arbutus	7.1	4	2.5	42	12,500

**85% of theoretical capacity was used as a proxy for practical capacity in the EMME model.*

In addition to the service assumptions for the rapid transit alternatives, there were a number of significant transportation network assumptions that were included in the future horizons in the model. These included projects committed as part of the Mayors' Council Vision for Transportation.

An inventory of notable future network assumptions in the RTM3 future horizons includes the following:

- **3rd Seabus –** With peak service frequency increasing from 15 minutes to 10 minutes.
- **Expo, Millennium and Canada Line Capacity Increases –** With more frequent and longer trains to accommodate ridership growth.
- **New B-Line Services –** Implementation of 11 new B-Line express transit services.
- **Broadway Subway Project –** To extend the Millennium Line from VCC-Clarke Station to a new terminus at Arbutus St.
- **Pattullo Bridge Replacement –** To replace the existing Pattullo Bridge with a new four-lane un-tolled crossing.

Tolls have been removed from the Port Mann and Golden Ears bridges, and no additional pricing assumptions such as comprehensive bridge or distance-based pricing have been applied in the model.

8.1.8 Updated Forecast Results

Daily weekday ridership forecasts for years 2030 and 2045 were developed using TransLink's RTM3 to evaluate the attractiveness/desirability of each of the transit options.

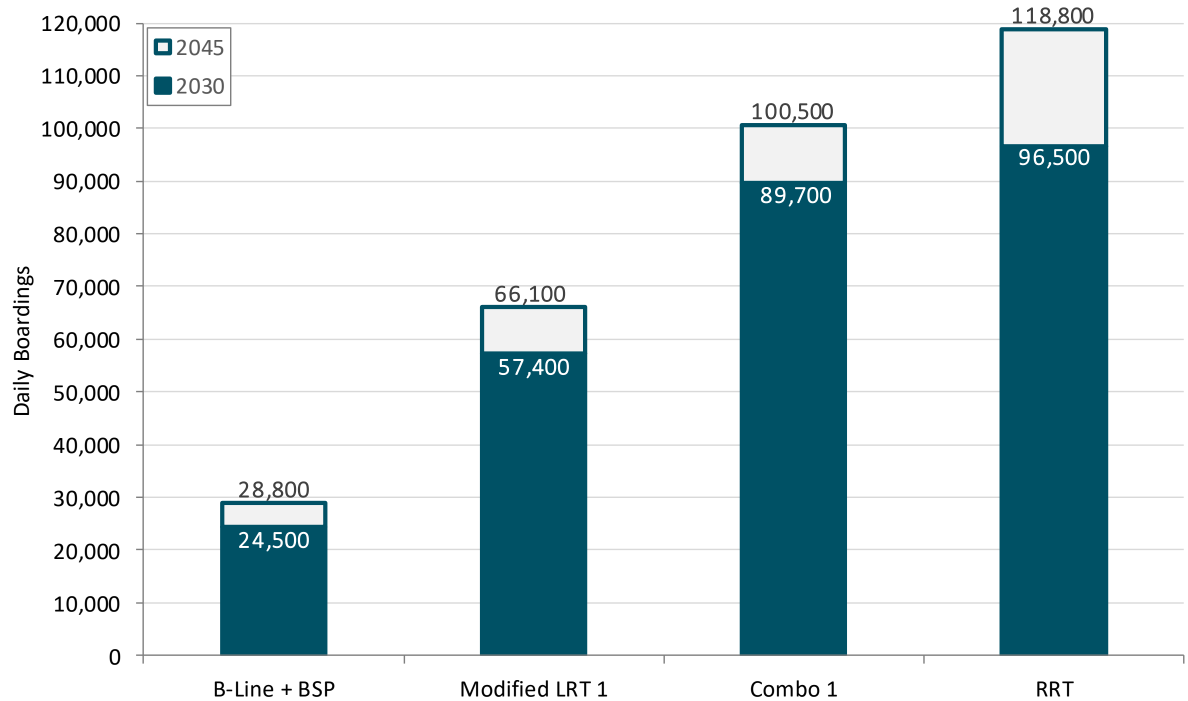
Ridership for each time of day assignment (AM, MD, and PM peak hours) was calculated as the total trips with a start and/or end point within the newly constructed alignment for each of the technology options. For example, the RRT ridership was calculated for the segment between Arbutus and UBC by taking the westbound through ridership at Arbutus and adding all boardings west of this point. These were then expanded to a daily total using expansion factors calculated from the total observed transit volumes at the UBC screenline. The AM, MD and PM expansion factors are:

- **AM**: 1.62
- **PM**: 3.03
- **MD**: 9.72

Modelled daily ridership estimates for the Arbutus to UBC segment are shown in *Figure 8-9*. Estimates for the B-Line (BAU) transit scenario indicate that the B-Line will experience roughly 24,500 daily boardings in 2030. In 2045, the forecasts show that ridership on the B-Line will increase by 4,300 passengers, which is likely due to the B-Line's inability to accommodate increasing demand on the Broadway Corridor. By comparison, the Modified LRT 1, Combo 1, and RRT options all show considerably higher ridership potential based on improved travel times and capacities. As shown in the figure, the Combo 1 option performs better than the Modified LRT 1 option, while the RRT scores the highest number of boardings overall with an estimated 96,500 daily riders in 2030 and 118,800 daily riders in 2045.

Any alternative other than RRT would require a transfer from one transit sub mode to another. This carries a significant time penalty owing to the inconvenience of getting off a transit vehicle, travelling to another platform, waiting for the next vehicle and then trying to find a seat or space to board the vehicle. The transportation demand model weighs this transfer at approximately a 10-minute penalty which has a clear negative effect on ridership in addition to travel time and capacity. This penalty is applied uniformly across the region including trips transferring from any transit sub mode including bus, SeaBus, SkyTrain and others.

Figure 8-9: Rapid Transit Daily Weekday Ridership Forecasts for 2030 and 2045 (Arbutus to UBC Segment)



8.1.9 Mode Share Projections

Mode share estimates derived from the RTM3 model, as shown in *Figure 8-10* to *Figure 8-15*, were assessed for each of the technology options to determine their level of contribution towards attaining the sustainable mode share targets set forth by UBC, the City, and TransLink.

Given the large number of trips occurring regionally, it is expected that the alternatives would show little improvement to the regional mode share. At a regional scale, the overall transit modal shares range from 17.3 percent with the B-Line and Modified LRT 1 options to 17.5 percent with the Combo 1 alternative for the year 2030 (*Figure 8-10*). All alternatives are projected to increase transit mode share in 2045, with the Combo 1 and RRT options providing the greatest improvement to the regional transit modal share at an increment of 0.2 percent compared to the B-Line (*Figure 8-11*). Relative to the ridership experienced on the B-Line, it is projected that the Modified LRT 1 option will introduce 4,000 new daily transit trips across the region. The Combo 1 and RRT options, on the other hand, demonstrate greater potential for attracting new transit patronage with an estimated 16,000 and 13,600 new daily trips respectively.

Figure 8-10: Daily Mode Share Projection for the Region (2030)

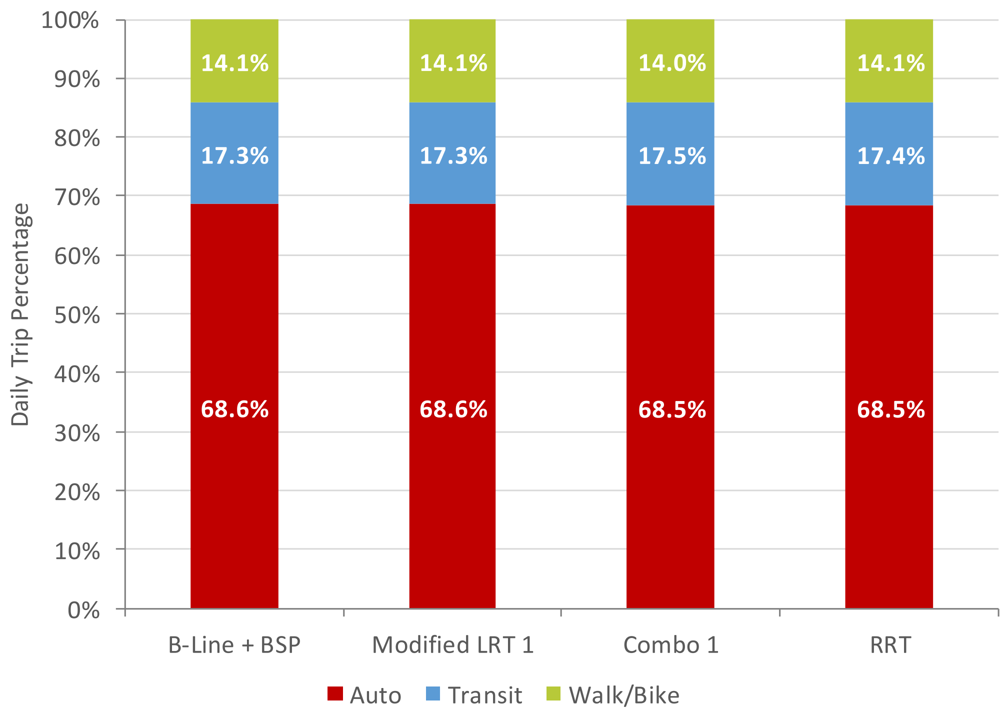
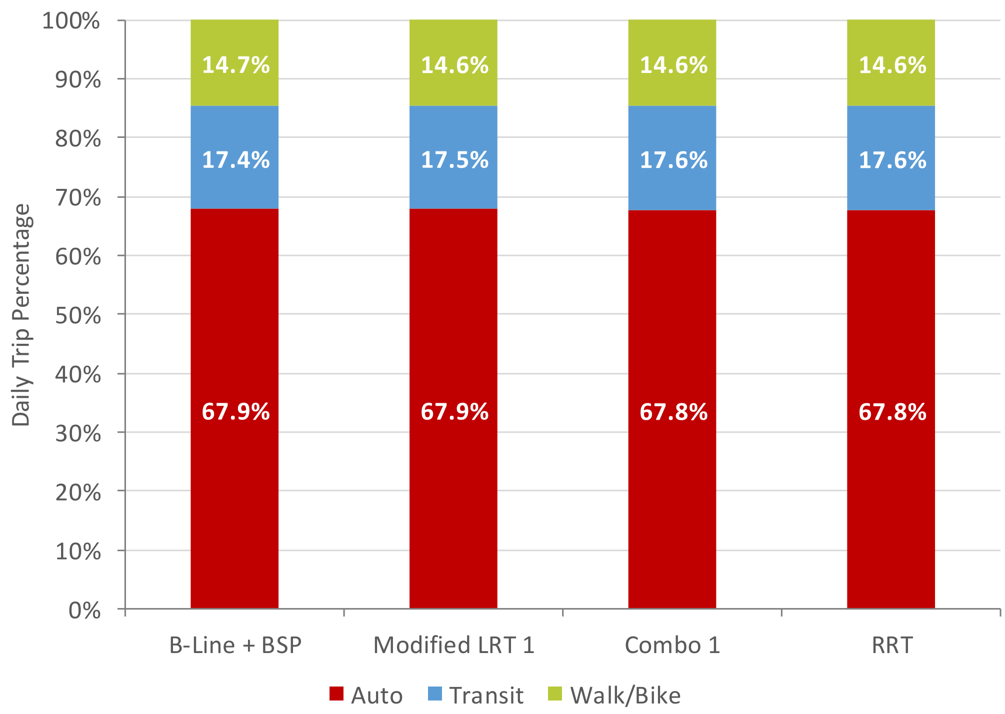


Figure 8-11: Daily Mode Share Projection for the Region (2045)



Mode share estimates for the City of Vancouver (*Figure 8-12* and *Figure 8-13*) area indicate that the Combo 1 alternative provides the greatest benefit to improving the transit mode share for both 2030 and 2045. Because the Combo 1 option extends from Main Street-Science World to UBC, it is expected that people residing in Vancouver would benefit from the additional rapid transit coverage provided by the Combo 1 option. These charts show that the

City will not achieve their sustainable transportation mode share targets. However, the City is pursuing other actions that will bring them closer to this target that are not considered in this analysis. This includes a reconsideration of land uses and densities along the Broadway corridor as well as the Jericho Lands major development site which could increase the transit ridership forecasts.

Figure 8-12: Daily Mode Share Projection for City of Vancouver (2030)

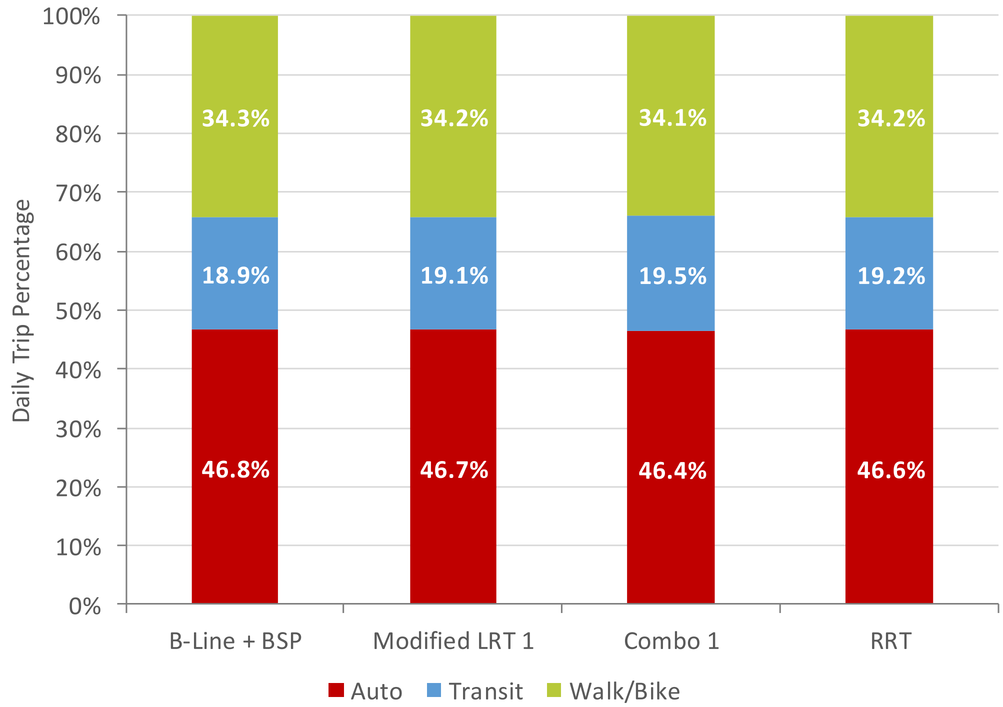
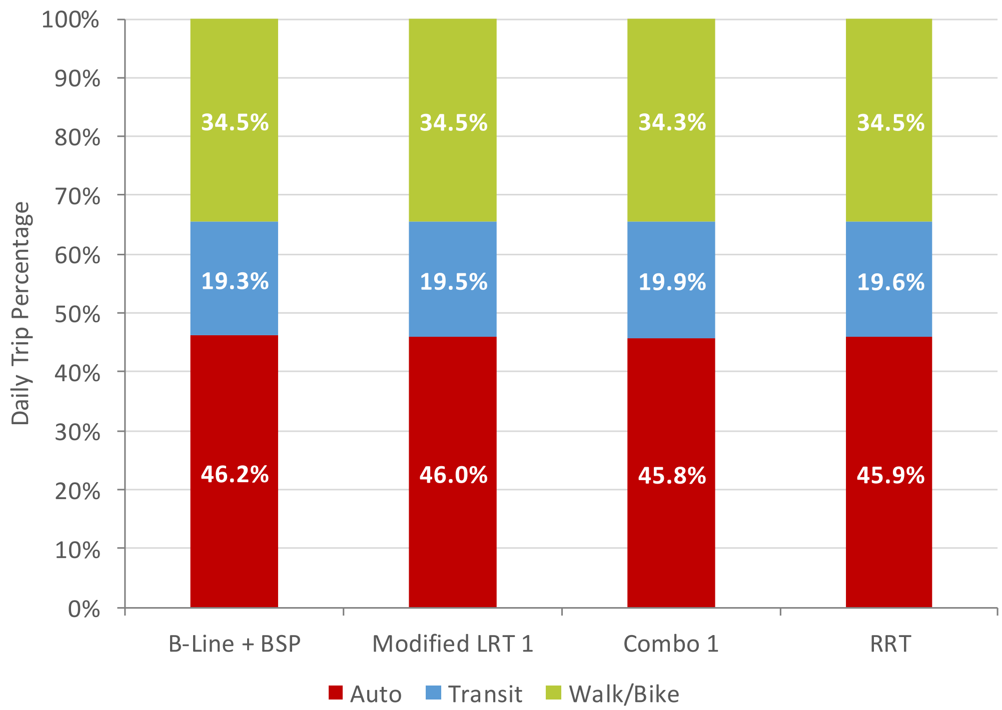


Figure 8-13: Daily Mode Share Projection for City of Vancouver (2045)



Mode share estimates for the UBC area showed that all alternatives would provide improvements to the share of transit trips and greater variation between the competing alternatives. Under the RRT alternative, UBC will see the largest upward effects on transit mode share with increases to 63.6 percent in 2030 and 65.3 percent in 2045, as shown in *Figure 8-14* and *Figure 8-15*.

Figure 8-14: Daily Mode Share Projection for UBC (2030)

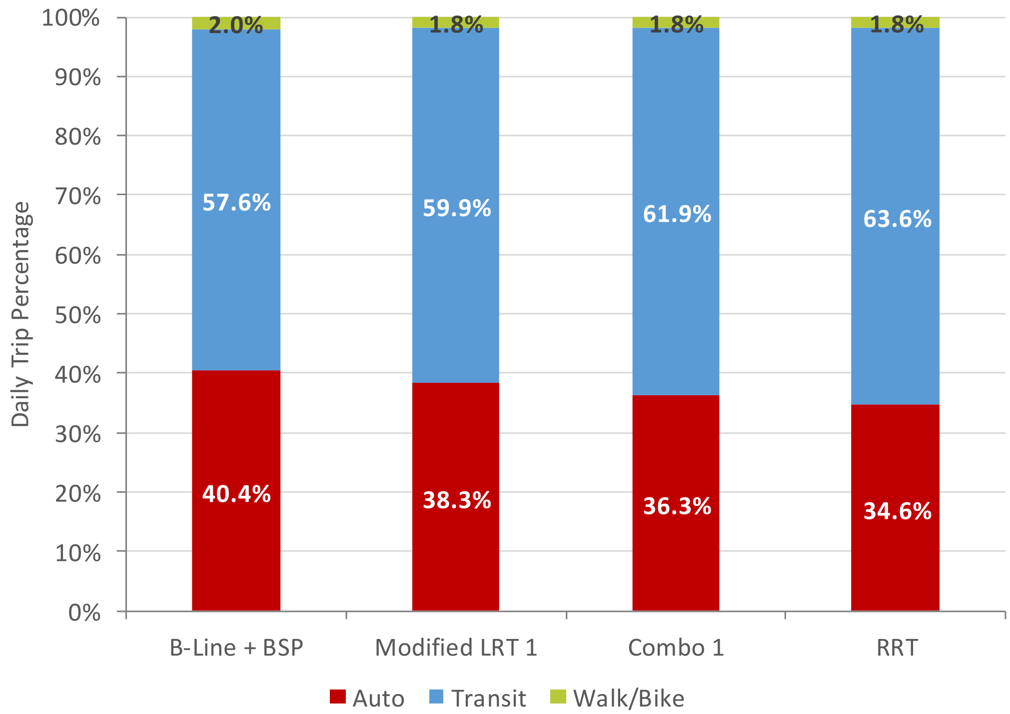
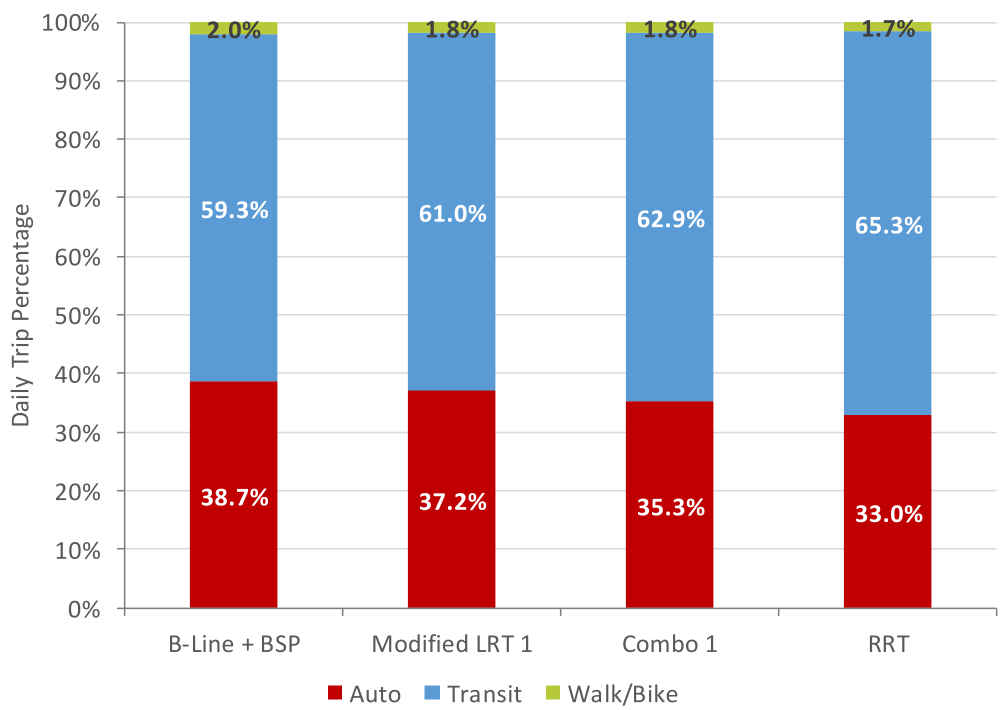


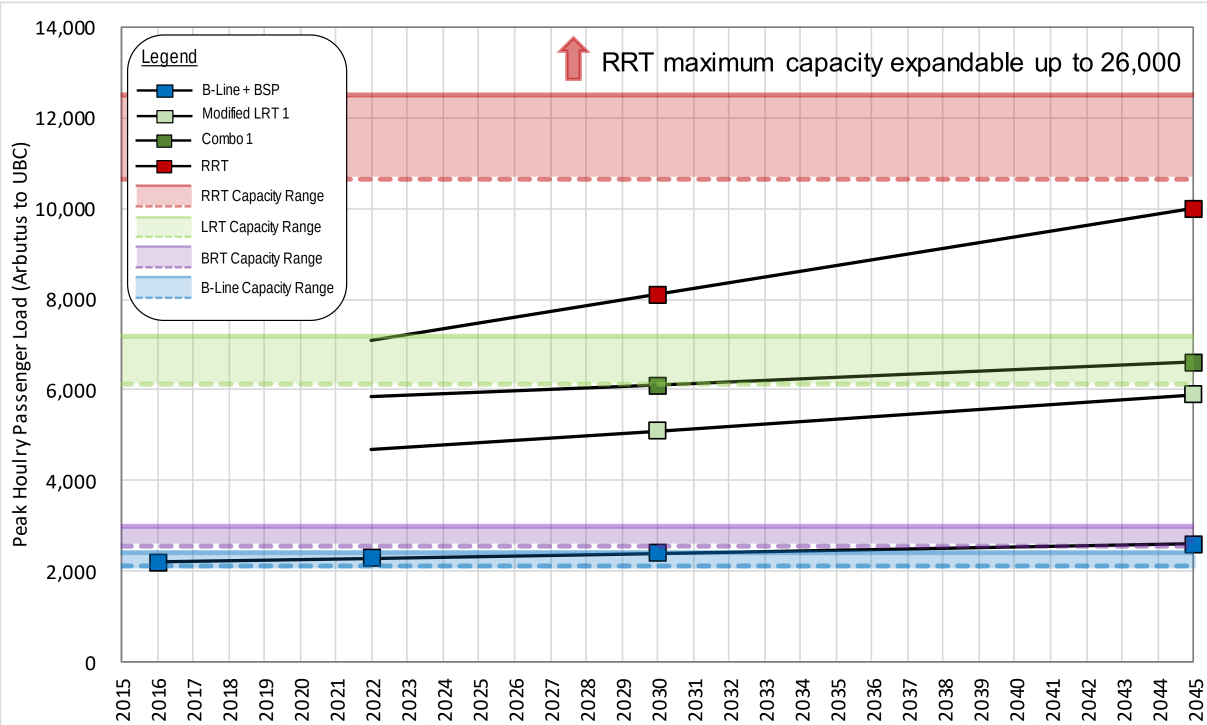
Figure 8-15: Daily Mode Share Projection for UBC (2045)



8.1.10 Peak Load and Load Profiles

Transit demand projections indicate peak passenger loads of 8,100 and 10,000 under the RRT scenario in 2030 and 2045 respectively. This indicates that LRT and BRT suppress demand in the Broadway corridor because of travel time and capacity constraints. Beyond approximately 2023, *Figure 8-16* shows that the demand generated by the RRT alternative exceeds the capacities of the other rapid transit systems. Given that the RRT service plan can accommodate up to 12,500 passengers per hour per direction, expandable to 26,000 pphpd, the RRT option is not expected to be capacity constrained even in 2045.

Figure 8-16: Peak Load Projection



Note: Solid line refers to the theoretical capacity, while the lower dashed line refers to the practical capacity. Practical capacity used in transit planning practice is typically 85% of theoretical.

Boardings, alightings, and passenger volumes for each transit alternative in 2045 and the B-Line alternative in 2030 are presented in *Figure 8-17* to *Figure 8-21*, with the solid red line representing the theoretical capacity and the dashed line referring to the practical capacity of each alternative. For each of the rapid transit alternatives, the general pattern is a large volume of through passengers at Arbutus that are travelling through to UBC. Presently, there is very little boarding and alighting activity at the intermediate stops between Arbutus and UBC. However, it should be noted that this could change given the considerable development potential along the corridor not represented in the current RTM3 land use assumptions. In all options, the westbound direction is the busiest during the AM peak with a significant number of people boarding at the transfer points, Commercial-Broadway and Arbutus, in particular. *Figure 8-17* suggests that in 2030, demand on the Broadway corridor would exceed the capacity of the B-line service. With the projected transit demand exceeding the capacity of the B-Line and all other buses running significantly above capacity in 2045 (*Figure 8-23*), the accompanying line-ups and pass-ups may discourage commuters headed to UBC from using transit services. Consequently, the Broadway Subway Project will be underutilized as those wishing to continue to their route using the 99 B-line are unable to do so as it is already at or over capacity. This is illustrated in the demand profile of the B-Line alternative in 2045 (*Figure 8-18*).

The demand profile for the Modified LRT 1 indicates that there will be high transfer activity at Arbutus with approximately 5,000 passengers transferring from the SkyTrain to LRT during the AM peak hour. Ridership forecasts for the Modified

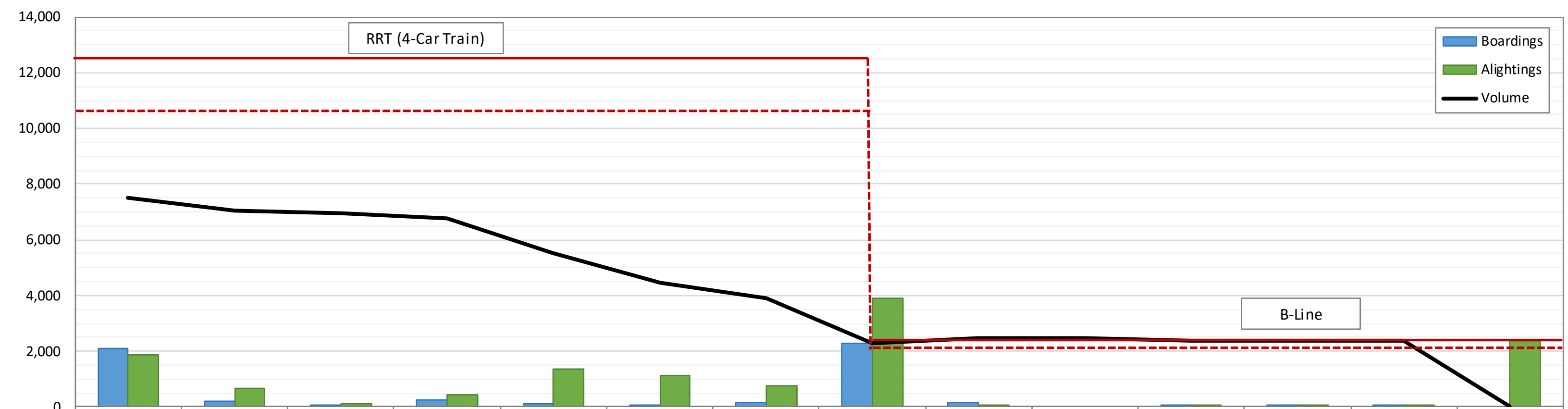
LRT 1 alternative demonstrate that the demand will approach the practical capacity of the LRT in 2045. Because the capacity of the LRT cannot be expanded any further, this option would not be able to provide sufficient capacity to accommodate future demand without impacts related to overcrowding and reliability.

Results for the Combo 1 alternative suggest that the majority of UBC-bound transit riders are transferring directly from the SkyTrain Expo Line to the light-rail transit service offered with the Combo 1 option at Main Street-Science World Station. As a result, the high passenger demand experienced on the LRT portion will exceed the practical capacity of the LRT by 2045, leading to overcrowding on the segment between Arbutus and UBC as well as decreasing utilization of the BSP SkyTrain segment with a transfer-free service between Main Street-Science World and UBC. Given that ridership forecasts are higher than LRT capacity, there will likely be queuing that occurs at Main Street-Science World and at Arbutus stations.

As illustrated in *Figure 8-21*, the RRT option is the only one that ensures that the BSP is well utilized from Commercial-Broadway to UBC. It should be noted that although the demand exceeds the practical capacity of the RRT between Commercial-Broadway and Cambie, the capacity of the RRT can be expanded as needed through the use of 5-car trains.

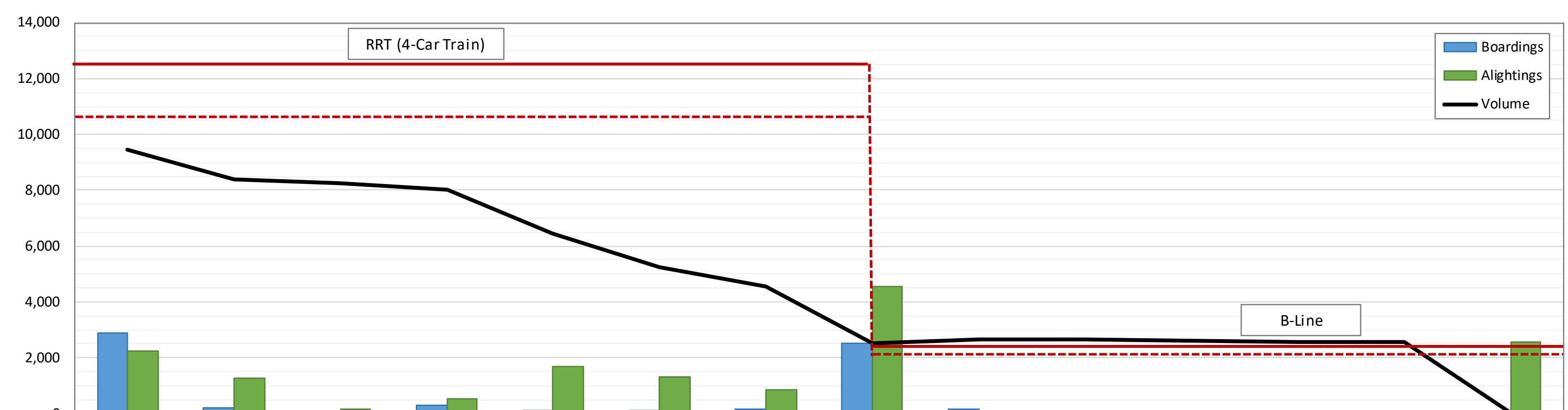
The peak load in this segment is generated with the RRT alternative which has the highest capacity, highest operating speed and no transfer. For consistency with previous analysis, a sensitivity test with a one car train for Combo 1 was analyzed. This scenario shows about a 40% decrease in ridership as the one car train is capacity constrained. *Appendix C* provides network volume plots that show the transit demand profiles for each of the alternatives for the broader network.

Figure 8-17: WB AM Peak Demand Profile for B-Line (2030)



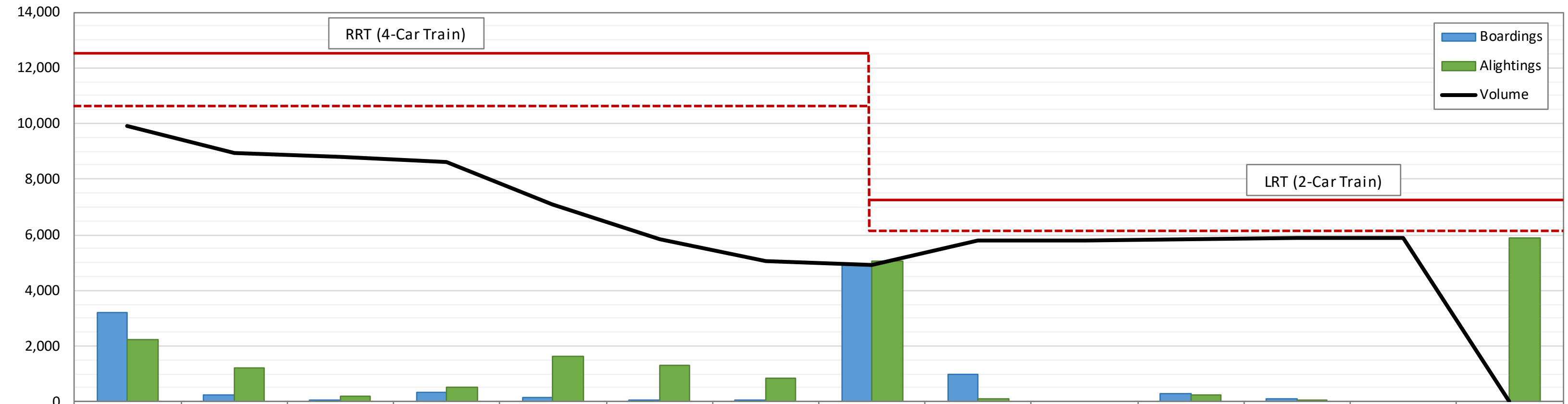
	Commercial-Broadway Station	VCC-Clark Station	Great Northern Way	Main	Cambie	Oak	Granville	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	2,110	210	20	250	90	80	170	2,290	170	0	20	20	10	0
Alightings	1,880	660	130	430	1,360	1,110	740	3,910	20	0	70	30	20	2,370
Volume	7,520	7,060	6,960	6,780	5,510	4,480	3,910	2,290	2,450	2,450	2,400	2,390	2,370	0

Figure 8-18: WB AM Peak Demand Profile for B-Line (2045)



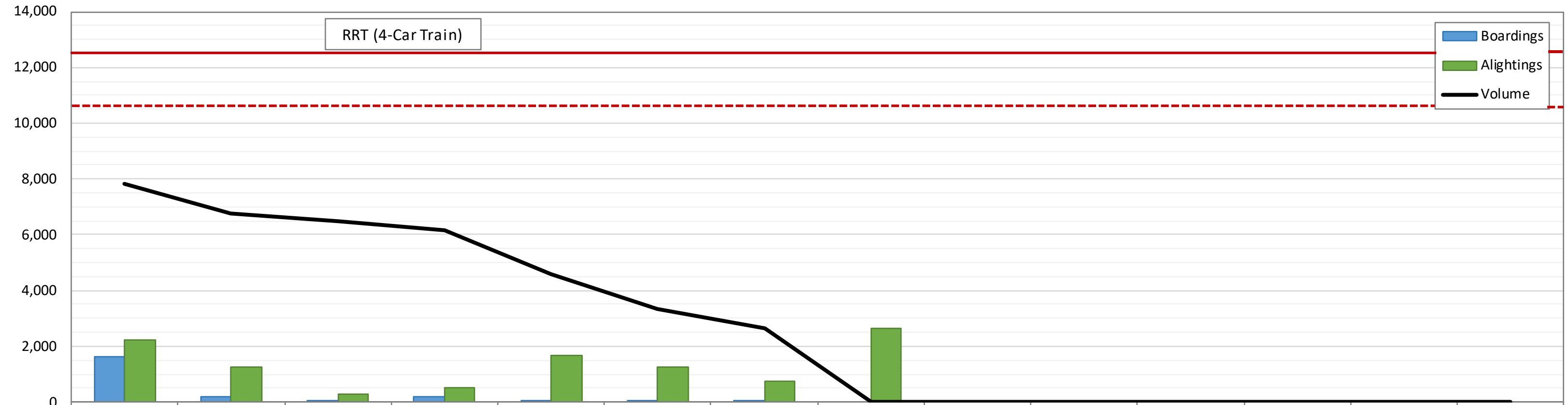
	Commercial-Broadway Station	VCC-Clark Station	Great Northern Way	Main	Cambie	Oak	Granville	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	2,870	220	20	280	130	90	180	2,520	150	-	20	20	0	-
Alightings	2,250	1,270	180	510	1,670	1,320	850	4,560	20	-	80	30	20	2,570
Volume	9,430	8,390	8,230	8,000	6,450	5,230	4,560	2,520	2,650	2,650	2,590	2,580	2,570	-

Figure 8-19: WB AM Peak Demand Profile for Modified LRT 1 (2045)

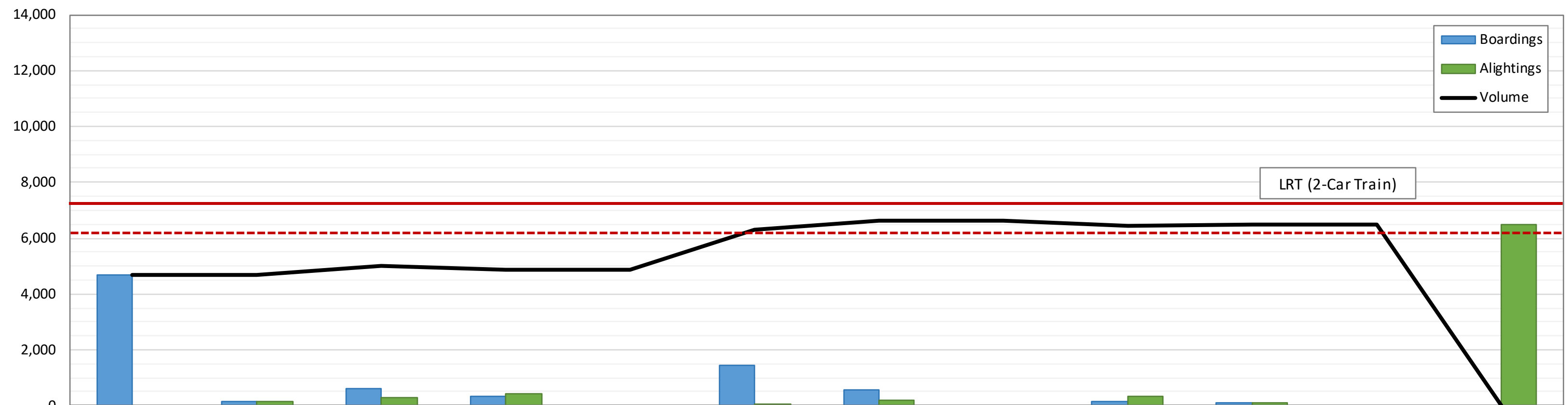


	Commercial-Broadway Station	VCC-Clark Station	Great Northern Way	Main	Cambie	Oak	Granville	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	3,220	260	20	310	130	60	30	4,900	980	-	290	120	-	-
Alightings	2,240	1,230	180	500	1,640	1,300	820	5,070	110	-	230	60	-	5,900
Volume	9,920	8,950	8,800	8,610	7,090	5,850	5,070	4,900	5,770	5,770	5,830	5,900	5,900	-

Figure 8-20: WB AM Peak Demand Profile for Combo 1 (2045)

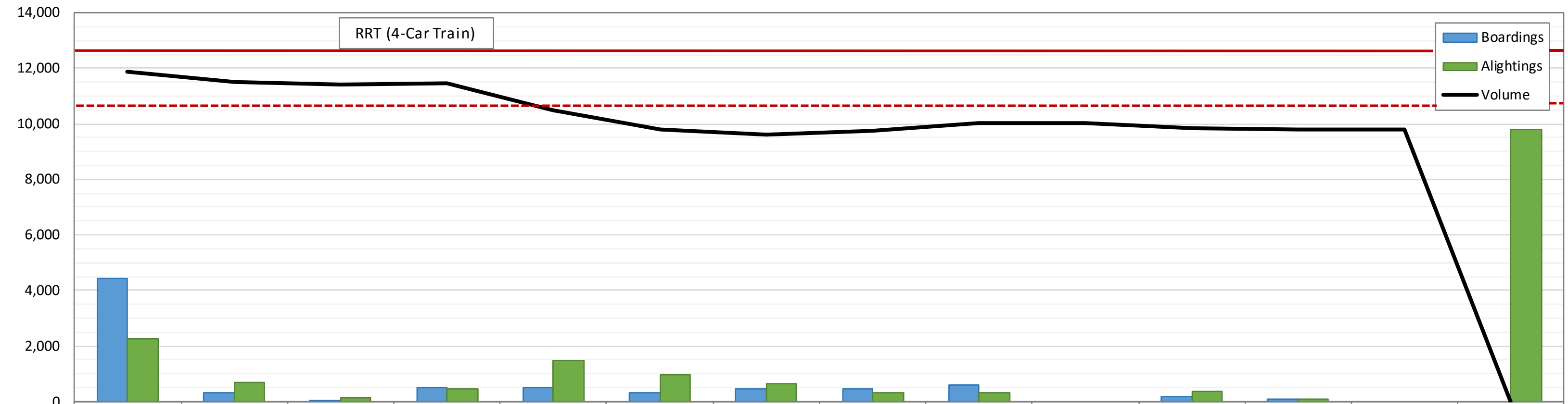


	Commercial-Broadway Station	VCC-Clark Station	Great Northern Way	Main	Cambie	Oak	Granville	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	1,630	210	10	200	50	50	20	-	-	-	-	-	-	-
Alightings	2,240	1,260	290	510	1,650	1,260	730	2,650	-	-	-	-	-	-
Volume	7,830	6,780	6,500	6,180	4,580	3,360	2,650	-	-	-	-	-	-	-



	Main St-Science World Station	Columbia	Olympic Village Station	Hemlock	Burrard	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	4,660	170	610	330	0	1,460	560	-	150	110	-	-
Alightings	0	160	290	430	0	70	200	-	320	80	-	6,500
Volume	4,660	4,670	5,000	4,890	4,890	6,280	6,640	6,640	6,460	6,500	6,500	-

Figure 8-21: WB AM Peak Demand Profile for RRT (2045)



	Commercial-Broadway Station	VCC-Clark Station	Great Northern Way	Main	Cambie	Oak	Granville	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	4,440	320	30	500	480	320	450	430	590	-	180	70	-	-
Alightings	2,250	690	150	440	1,480	970	660	310	320	-	350	90	-	9,820
Volume	11,900	11,520	11,400	11,470	10,470	9,820	9,610	9,740	10,010	10,010	9,840	9,820	9,820	-

8.1.11 Overcrowding on Parallel Corridors and Diversion

In order to better understand diversion for alternate corridors, a summary of the passenger load factors (PLF) for the transit services (i.e. volume-to-capacity ratios) was produced. The PLF was calculated by dividing the hourly passenger volume at the UBC screenline by the total hourly capacity for each route. The hourly capacity was calculated using bus frequency and TransLink's operational capacity (*Figure 8-22*) as defined in TransLink's Transit Service Performance Review (TSPR)[42]. Furthermore, the following crowdedness measures were adopted from TransLink's TSPR:

- Crowded: PLF ≥ 84%,
- Overcrowded: PLF ≥ 100%.

Figure 8-22: Bus-Based Vehicle Capacities

CROWDING GUIDELINES by Bus Type and Time Period

BUS TYPE	Peak	Off Peak
	Maximum Number of Passengers On-Board	
STANDARD TROLLEY	55	45
ARTICULATED TROLLEY	75	65
STANDARD BUS	50	45
ARTICULATED BUS	75	65
HIGHWAY COACH	47	47
MINI- BUS	20	20

Adapted from TransLink's Transit Service Guidelines.

For the 2045 horizon, all of the other parallel corridors are running above capacity (i.e. overcrowded) for all scenarios during the AM peak period except for RRT. Because of greater speed and capacity, RRT relieves crowding on parallel corridors to a greater extent compared with other alternatives.

Table 8-8 provides a summary of the combined average volume-to-capacity ratios for the parallel corridors serving UBC which shows that RRT provides the most congestion relief to the other corridors. *Figure 8-23* to *Figure 8-26* provides a breakdown of these corridors by route which shows more details of overcrowding on parallel bus routes.

[42] *TransLink's 2016 TSPR, Appendix B: Report Definitions and Assumptions, pg.5.*

Table 8-8: Passenger Load Factor by Corridor (2045 WB AM)

Scenario	Rapid Transit	Bus Corridor			
		Chancellor Blvd	University Blvd	16th Avenue	SW Marine Dr
2045 B-Line + BSP	n/a	179%	174%	134%	106%
2045 Modified LRT 1	86%	129%	94%	85%	98%
2045 Combo 1	95%	114%	123%	78%	92%
2045 RRT	83%	85%	53%	52%	67%

Figure 8-23: Passenger Load Factor by Transit Service for B-Line + BSP Option (2045 WB AM)

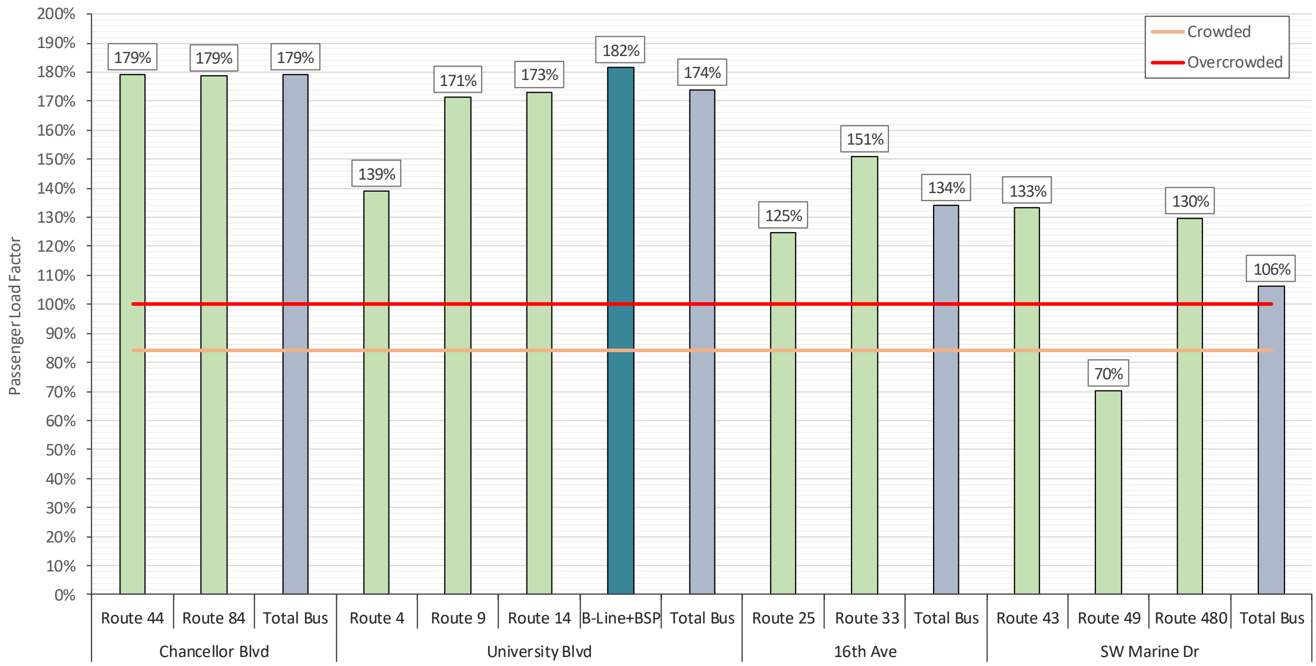


Figure 8-24: Passenger Load Factor by Transit Service for Modified LRT 1 Option (2045 WB AM)

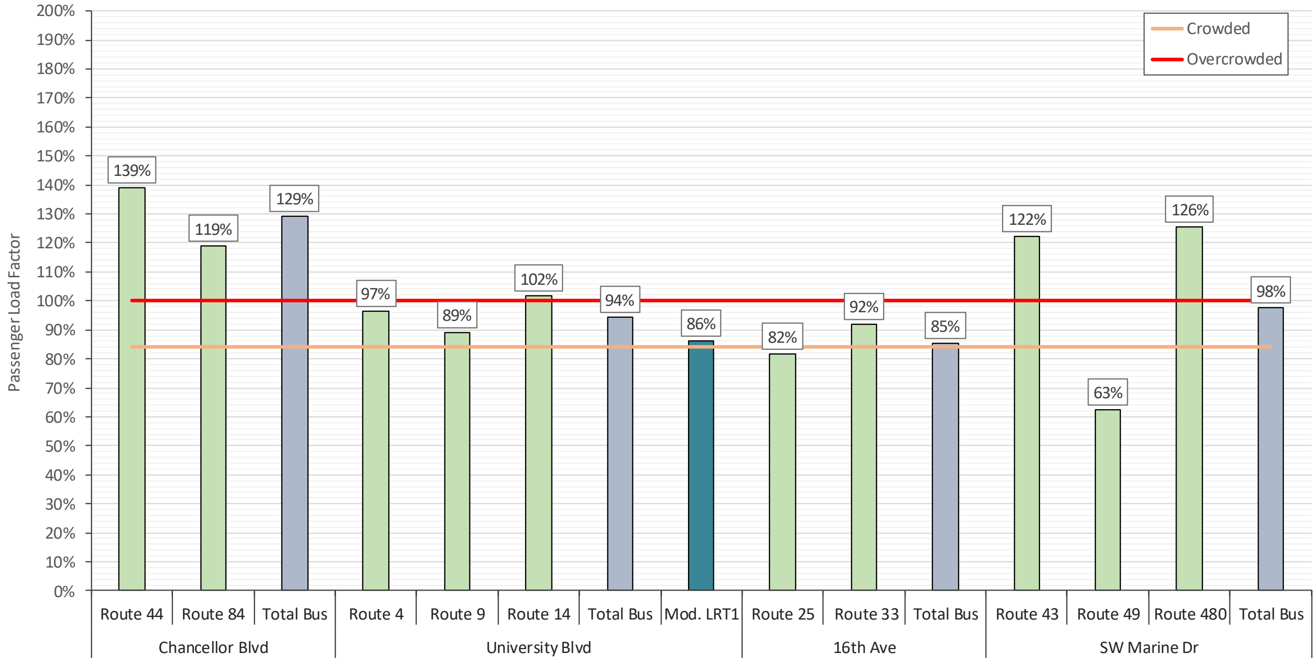


Figure 8-25: Passenger Load Factor by Transit Service for Combo 1 Option (2045 WB AM)

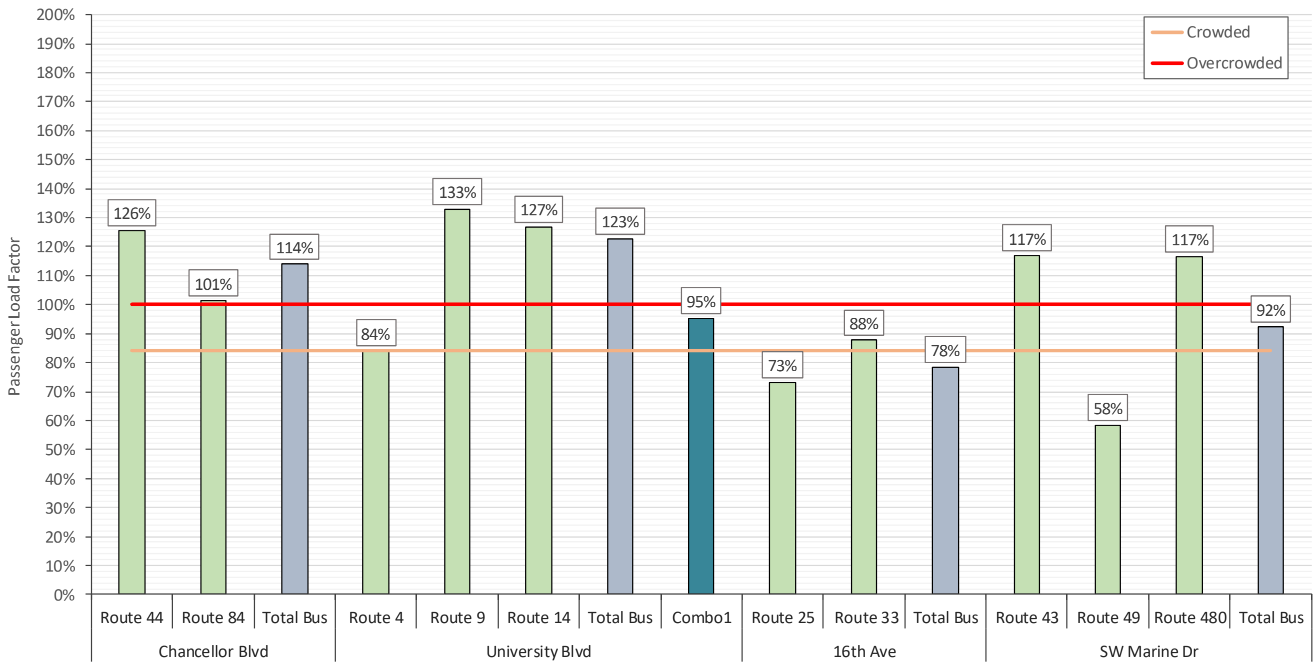
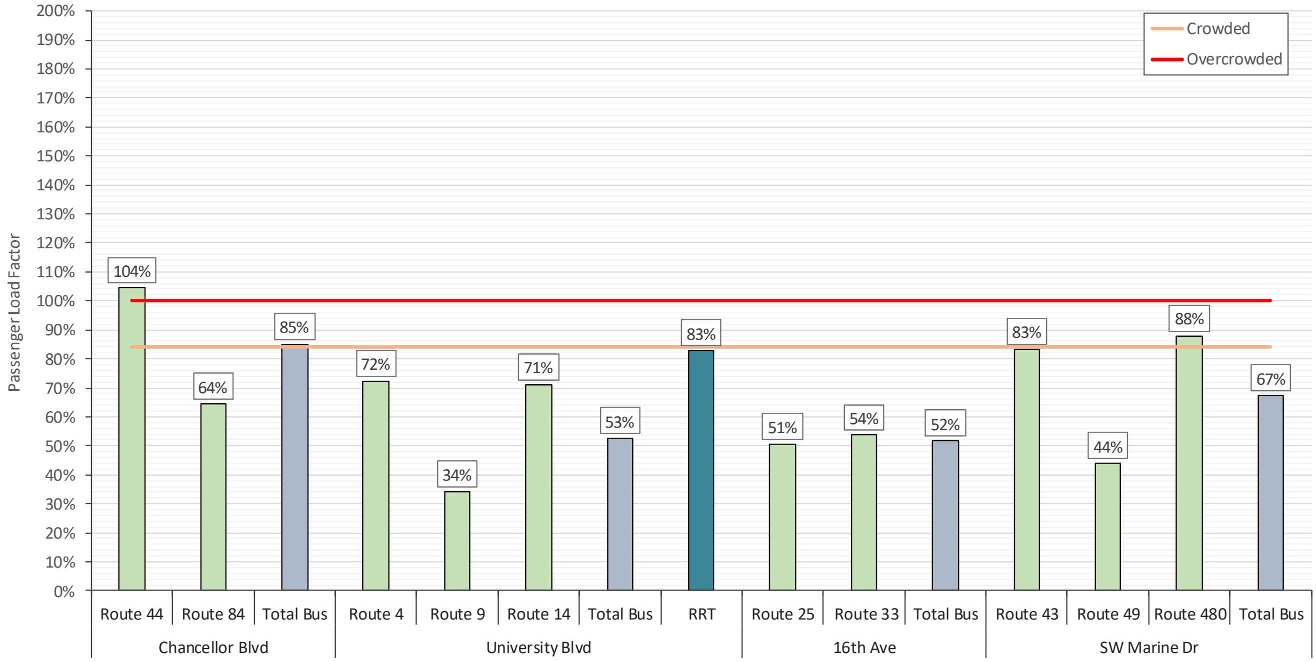


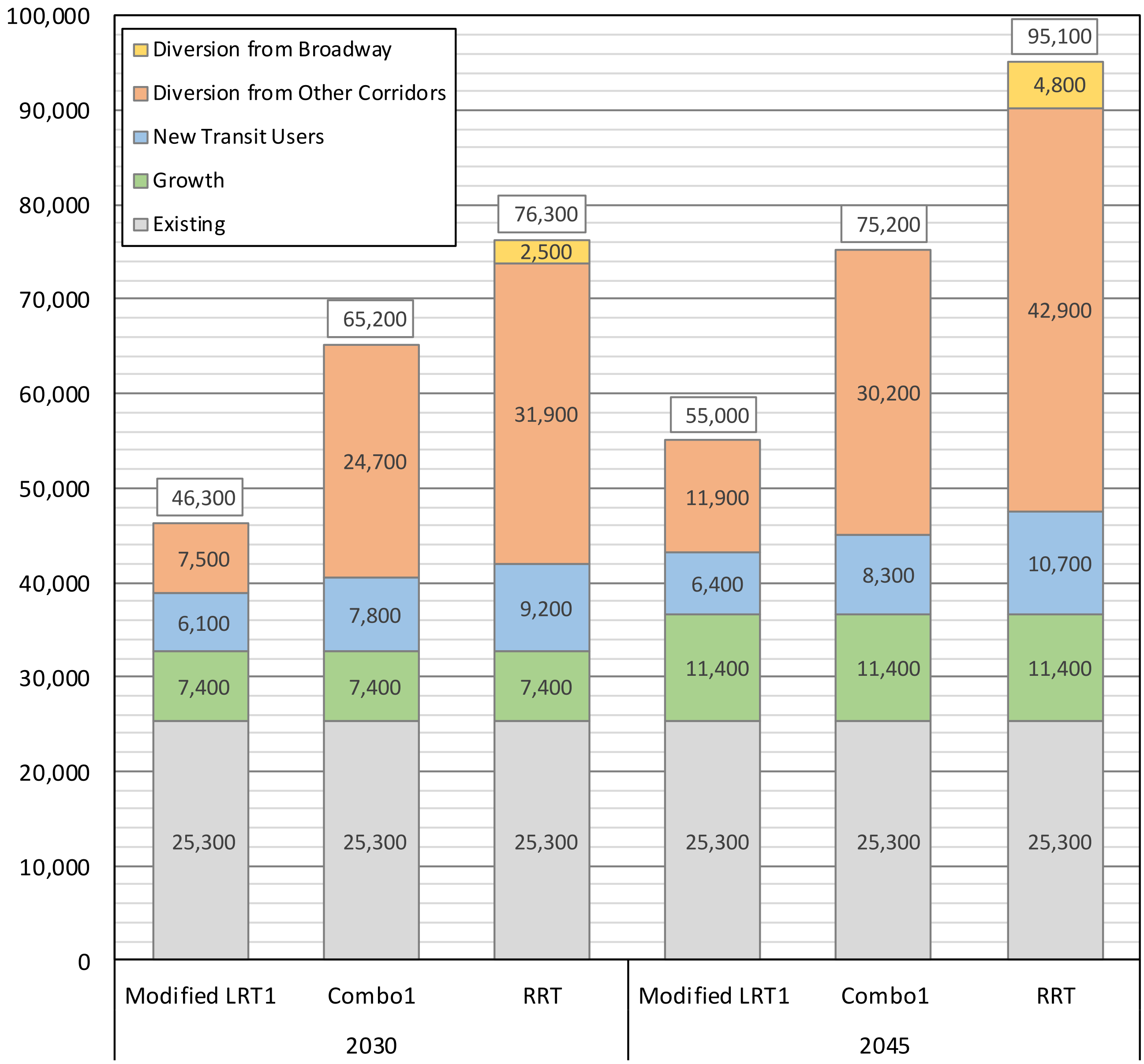
Figure 8-26: Passenger Load Factor by Transit Service for RRT Option (2045 WB AM)



To further understand the alternatives, a component breakdown of the volume forecast was developed. The analysis was completed at the UBC Screenline with the components of the volume forecast defined as follows and illustrated in *Figure 8-27*:

- Existing: Existing B-Line Volume at UBC Screenline
- Growth: Anticipated growth in transit demand due to growth in land use
- New Transit Users: Anticipated increase in volume due to induced travel, mode shift, and other changes in travel patterns due to that scenario
- Diversion: Diversion from other Broadway bus routes and other corridors (SW Marine Dr, 16th Avenue, and 4th Avenue)

Figure 8-27: Components of Ridership Growth for Rapid Transit Alternatives



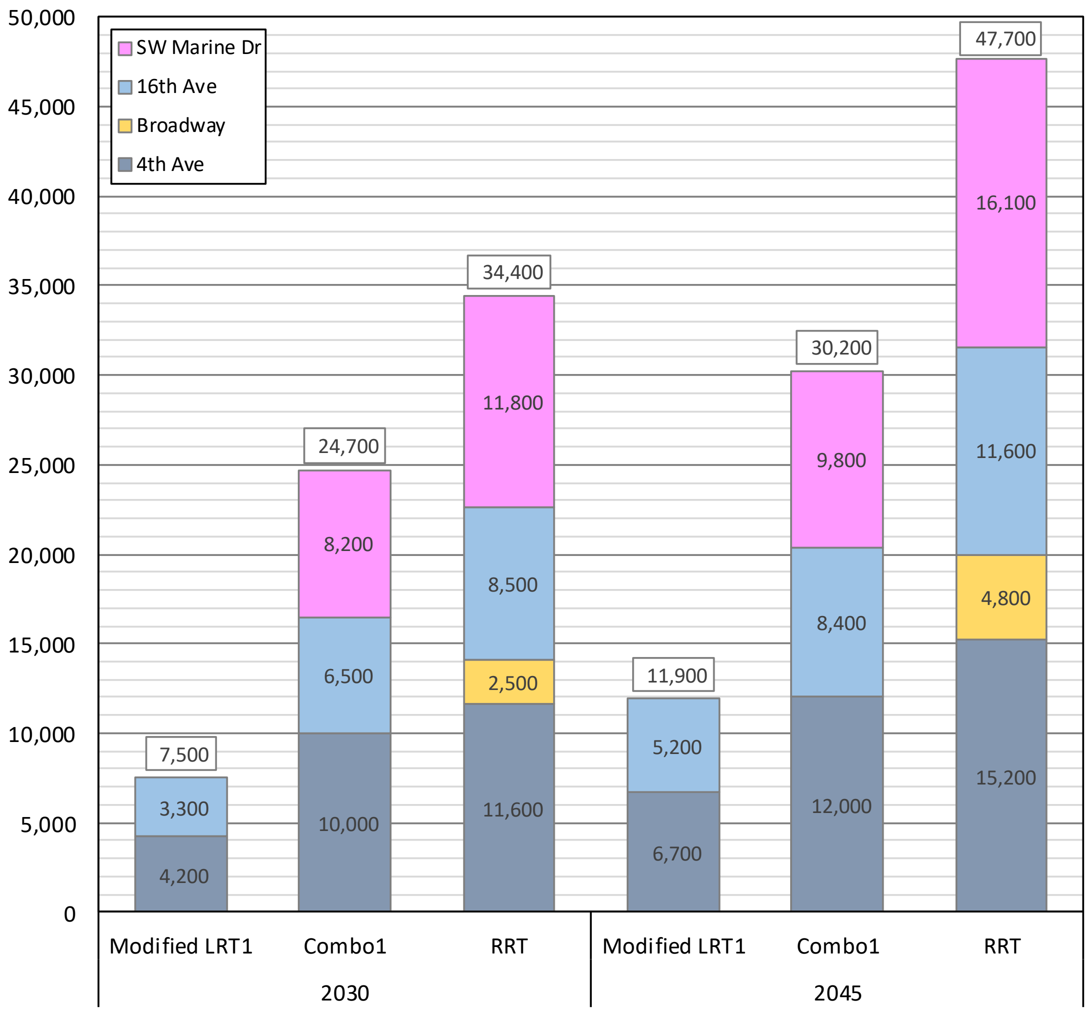
By definition, the existing volume component is consistent across the alternatives and horizon years, and the growth component is consistent across the alternatives within each horizon year.

The new transit users or redistribution component captures the increase in ridership due to travel pattern changes. The model's distribution component takes trips produced and attracted based on each zone's land use information and balances them to produce a full trip table where each trip produced is matched with an attraction (destination) location. This balancing process allocates trips based on the relative cost to travel between each zone in the model, where zones that are more accessible to each other will attract a larger portion of their produced trips than less accessible zones. The balancing procedure is calibrated to observed behaviour from the regional trip diary to represent peoples' willingness to accept travel costs when choosing a destination. On top of natural growth on the existing infrastructure due to changes in population and employment, there is a component based on the increased accessibility of zones served by the improved rapid transit infrastructure. The improvement in relative accessibility of these zones attracts trips from further away that may have chosen a different destination previously. In addition, there is a component of these trips that now choose the transit mode instead of alternatives. In this analysis, we combine both of these effects in the redistribution component of the growth forecast. Although this is a difficult change in travel patterns to observe and measure in the real world as it happens slowly over time, there is evidence from the trip diary and traffic and transit counts that speaks to this. Perhaps the best rapid transit example is the Canada Line, which has seen significant growth in travel, some of it based on redistribution which again is difficult to measure.

The largest component to increase volume over existing is ridership diversion from other corridors. Significant diversion is captured, specifically for the RRT, due to significant capacity increases, travel time savings, and reliability of service. By 2045, as congestion continues to increase, half of the RRT volume is anticipated to be from diversion from other routes and corridors. The Modified LRT 1 and Combo 1 alternatives do not provide the same level of capacity increases and travel time savings as the RRT, and therefore see lower diversion and total volumes. Note that part of this diversion is derived from increased capacity on the rapid transit service, but also the fact that bus-based services on the other corridors become significantly overcrowded in the future. As such, any improvements in capacity within this study area will attract ridership from diversion.

The estimates of diversion were further broken down by corridors: SW Marine Dr, 16th Avenue, Broadway, and 4th Avenue as shown in *Figure 8-28.* The Modified LRT 1 diversion is split primarily between 16th and 4th Avenue. The Combo 1 diversion, by 2045, is almost 1/3 from SW Marine Dr, 16th Avenue and 4th Avenue. The RRT pulls about a third of its diversion from both SW Marine Dr and 4th Avenue, about a quarter from 16th Avenue, and the remaining from the other Broadway bus routes. The RRT is the only alternative to pull significant diversion from the local bus routes on Broadway, as it is the most attractive and the only alternative that does not introduce a transfer at Arbutus.

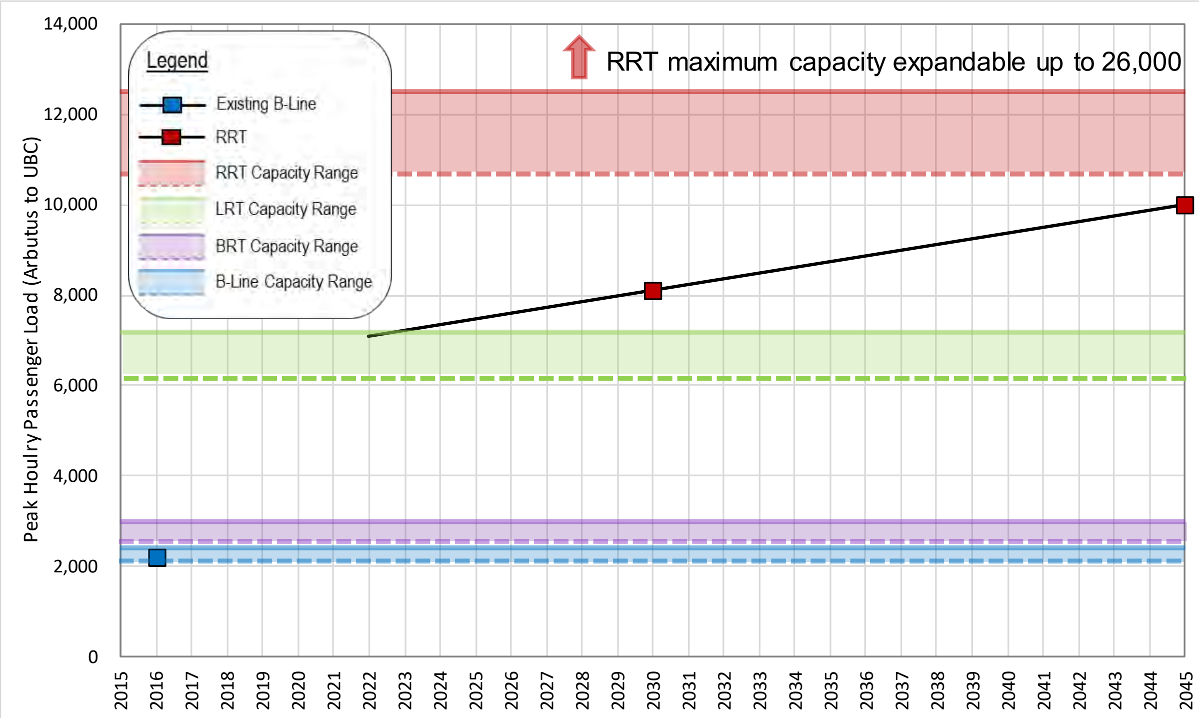
Figure 8-28: Contribution of Diversion by Corridor



8.1.12 Overcoming Capacity Challenges

With investment in SkyTrain to UBC, the RRT is forecast to carry 10,000 pphpd at the UBC screenline in 2045 which equates to approximately 118,800 corridor boardings (Arbutus to UBC) on a daily basis. This represents potential transit demand as the service levels attract the highest likely ridership along this corridor. At these levels, only RRT would meet this capacity requirement as shown in *Figure 8-29,* which shows assumed capacities for BRT, LRT and RRT technologies. Capacity for BRT would be exceeded today and LRT would be exceeded in approximately 2023 showing that only RRT would be suitable for long-term, future-proof investment in rapid transit. LRT ridership is forecast at about 60% that of RRT, partly because of slower travel times and the transfer penalty, but also because of capacity limitations. The increased speed, reliability and capacity of RRT attracts more ridership from latent and suppressed demand and better serves total demand along this corridor.

Figure 8-29: AM Peak Hourly Ridership at UBC Screenline to Meet Regional Sustainable Mode Share Target



Using capacity as a filtering criterion, based on the assumption that sufficient transit capacity is fundamental to meeting the travel demands that are anticipated in this corridor in the future and helps meet mode share and VKT targets, RRT is the only option which would qualify.

In considering all possible methods for meeting demand, the idea of a second LRT corridor was considered as another option that was not part of the 2012 Phase 2 Study. Since ridership for SkyTrain drew riders from other corridors and ridership demand of a single LRT line experienced capacity issues within 15 years (2045), a network approach with two LRT lines was considered. Four alignment variations were analyzed, all of which connect Arbutus Station to UBC and added LRT along the 41st Ave corridor to either connect with the Canada Line at Oakridge-41st Ave station or the Expo Line at Metrotown station.

8.1.13 Land Use Sensitivity

A transit supportive land use scenario was developed with inputs from UBC and City of Vancouver and run as a sensitivity test applied to the 2045 RRT Scenario. The RRT technology was chosen for this sensitivity scenario since both LRT options are over capacity and would not likely result in significant increases to transit ridership whereas RRT has capacity to absorb increased ridership due to increase land use density. In this case, both agencies applied higher rates of growth to households, population and employment for zones near the rapid transit stations. Population differences are shown in *Figure 8-30* with differences in households and employment provided in *Appendix D*. Similar to the Broadway Plan currently underway, the City would look for opportunities to integrate new housing, jobs, and amenities around future rapid transit. A public process would need to be conducted to determine the appropriate growth in the corridor. However, based on assumed land use changes implemented elsewhere in the City, there is a 3.1% increase in daily ridership on the RRT line but a 1.0% decrease in the peak load (which occurs in the WB direction during the AM peak period). The results of the sensitivity test are summarized in *Table 8-9*. Note that although there are plans to develop the Jericho Lands, the Musqueam-owned golf course lands, and the Musqueam Block F First Nations property, the land use assumptions for this sensitivity test does not include the growths that would be expected with these developments due to the uncertainties regarding the future land use.

Table 8-9: Ridership Impacts of Future Land Use Intensification

2045 RRT Scenarios			
	Base Land Use	Transit-Supportive Land Use	Difference (%)
Peak Load	9,800	9,700	-1.0%
Ridership Forecast	118,200	121,900	3.1%

The decrease in peak load is explained by the location and magnitude of changes in the land use as follows:

- At UBC, there is a significant increase in population and households (~60%) and a smaller increase in employment (~5%).
- Within Vancouver, the increase in population, households and employment is around 1.5%.
- The main drivers of the changes are the population and household increases at UBC.
- The increase in population (and households) at UBC is not only able to fill the new employment at UBC, but will also compete for the existing employment.
    - These trips are within UBC and would replace commuting trips originating from outside UBC (i.e. potential peak direction RRT trips)
    - Less commuting trips from outside UBC results in a reduction in the peak load.

The increase in daily ridership is also driven by the increased population and households at UBC. As the population and household increases are significantly greater than the employment increase, there is a significant increase in off peak direction travel on the RRT (i.e. EB in the AM and WB in the PM). The reduction in peak direction and increase in off peak direction transit travel is also shown in the transit volume difference plot in *Figure 8-31*. This plot also shows that there is a significant increase in transit usage in the other corridors serving UBC including 4th Ave, 16th Ave and Marine Dr.

Figure 8-30: Population Differences between 2045 Base and Transit-Supportive Land Use Scenarios

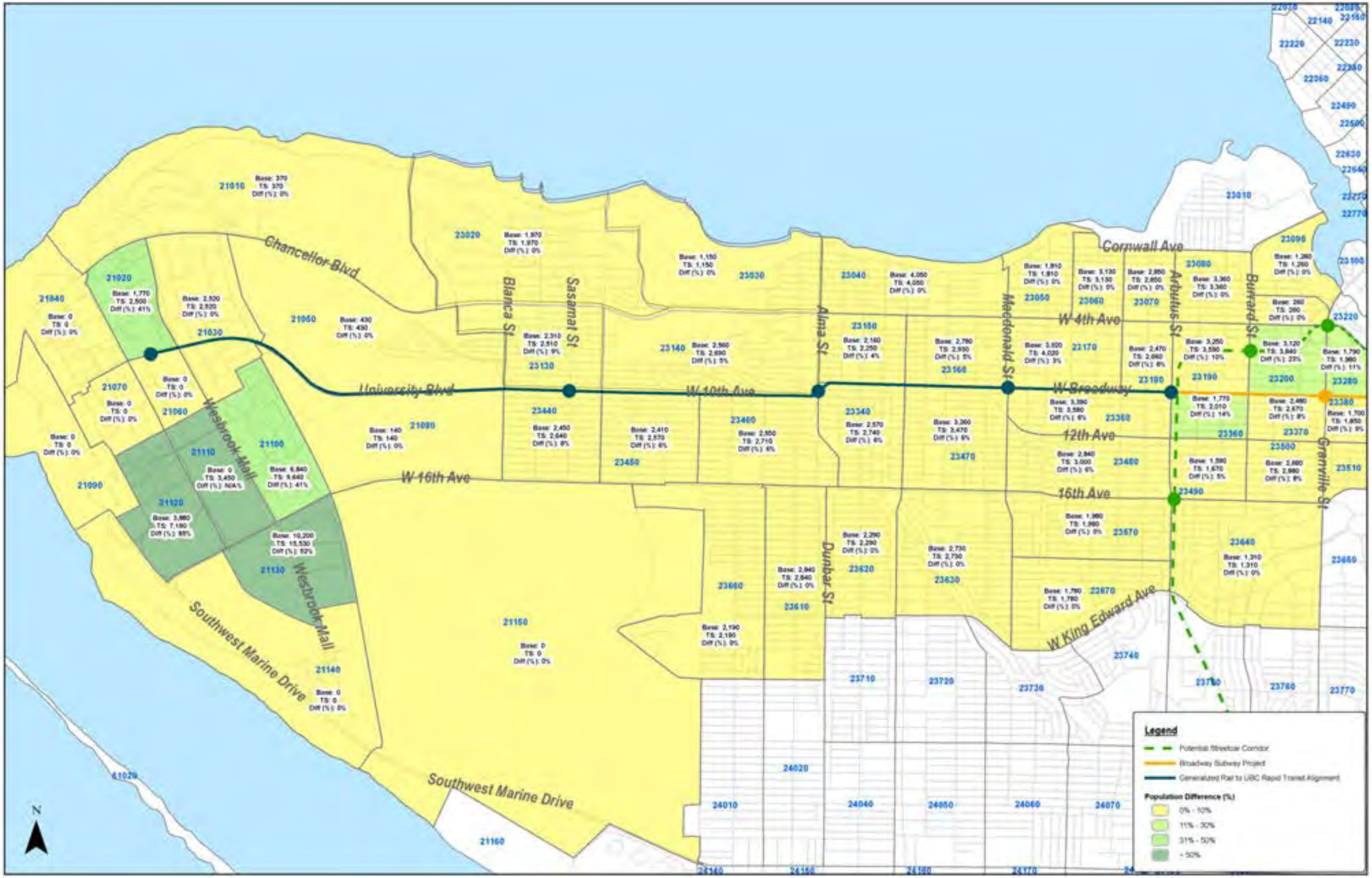


Figure 8-31: Transit Volume Difference Plot with RRT with Transit-Supportive versus Base Land Use

8.2 UPDATED COST ESTIMATES

8.2.1 Approach & Methodology

This section provides a high-level estimate of construction costs for each of the rapid transit alternatives. Publicly available construction costs for recently completed rapid transit lines (Evergreen Line) or the business cases for planned rapid transit lines (BSP and Surrey LRT) were used to produce updated construction cost estimates for the three rapid transit projects for the Rail to UBC Rapid Transit Study corridor. The prior "Capital Cost Summary" for the Evergreen Line Project dated 2010 was assessed comparing the breakdown of construction cost estimates for the Modified LRT 1 and RRT options from the 2012 Phase 2 Evaluation and more recent as-constructed costs from the Evergreen Line and Canada Line. This information was used to develop per unit rates for guideway/tunnel construction, stations, vehicles, property, etc.

Construction costs from the Evergreen Line are based on a Ministry of Transportation and Infrastructure (MoTI) public information release entitled "Evergreen Line Project – Project Financials", (2016). The only financial numbers were included in a single slide – "Financial Breakdown", summarized in *Table 8-10*.

Table 8-10: Evergreen Line – Forecast Financials – 2016

	2016 Forecast Cost	
Design-Build Contract Value o **Guideway (elevated, tunnel, at-grade)** o **Stations, Maintenance Yard** o **Design, Construction, Testing, Commissioning, Financing**		$925M*
Owner Costs – Municipal Construction	$42M	
Project Management (12%)	$110M	
TransLink Support	$26M	
Subtotal		**$178M**
SkyTrain Vehicles		$100M
Property Acquisition**		$160M
Total MoTI Forecast Cost		**$1,363M**

**MoTI provided no breakdown of how this Design-Build Contract Value was derived.*

***Assumed based on order-of-magnitude property requirements and land values.*

However, significant property, construction and material supply cost increases have been experienced between 2016 and 2018. This was especially demonstrated on May 1, 2018 when the Government of BC released revised cost estimates for the Broadway Subway Project (BSP) and the Surrey LRT projects. It is therefore evident that the Evergreen Line design / construction values are low if used as reference costs. The Evergreen Line forecast financials do however provide a practical breakdown to forecast cost elements for the Millennium Line extension to UBC.

8.2.2 Guideway Unit Costs

The May 1, 2018 press release provided the overall project cost estimates as shown in *Table 8-11*.

Table 8-11: Government of BC Press Release Project Cost Estimates (2018)

Project	Guideway Type	Guideway Line	Length	Estimated Cost	Total Cost / km
Broadway Subway Project	Tunnel RRT	VCC-Clark to Arbutus	5.8 km*	$2,830M	$490M / km
Surrey LRT	At-Grade LRT	104 Ave / King George Blvd	10.5 km	$1,650M	$160M / km

**Note: This includes 1 km of at-grade and elevated track from the VCC-Clark Station to the Great Northern Way tunnel portal.*

The guideway unit costs were estimated by using the Evergreen Line forecast financials breakdown and applying the revised government released estimates as milestone costs for both the BSP Tunnel RRT and Surrey at-grade LRT.

Using the 2010 Capital Cost Summary guideway cost breakdown for Modified LRT 1 vs. RRT (Tunnel + Elevated + At-Grade) and using *Table 8-11* cost estimates, a ballpark breakdown of costs was generated for the tunnel RRT, assuming a Tunnel RRT Station cost of $100M as shown in *Table 8-12*.

Table 8-12: Tunnel RRT Cost Breakdown

Estimated Government Cost (2018)	$2,830M	
Net Construction Costs without Tunnel/Guideway (includes stations, project management, property acquisition, contingency, and inflation during construction)	$(1,890M)	
Estimated Tunnel/Guideway Ballpark Construction Cost	$940M / 5.8 km	= **$160M / km**

Similarly, a ballpark breakdown of costs was generated for the at-grade LRT assuming an at-grade LRT Station cost of $5M (*Table 8-13*).

Table 8-13: At-Grade LRT Cost Breakdown

Estimated Government Cost (2018)	$1,650M	
Net Construction Costs without Guideway (includes stations, project management, property acquisition, contingency, and inflation during construction)	$(930M)	
Estimated at-grade LRT Ballpark Construction Cost	$720M	/ 10.5 km = **$70M / km**

The ballpark estimated unit costs combining information for both RRT and LRT are then summarized in *Table 8-14*.

Table 8-14: Ballpark Unit Costs (2018)

Guideway Component		2018 Ballpark Unit Cost
Tunnel + Guideway RRT	=	$160M / km
At-Grade LRT	=	$70M / km
Stations – LRT (At-Grade) **RRT (Tunnel)**	=	$5M ea $100M ea
Maintenance Yard – LRT	=	$350M ea*
Maintenance Yard – RRT	=	$190M ea

** Stand-alone Maintenance Yard, not a satellite of another system. Also, assumed same size maintenance yard for Modified LRT 1 and Combo 1.*

These Ballpark Unit Costs were used to estimate 2018 project costs for the following system options:

- RRT (Tunnel) – Arbutus to UBC
- Combo 1 (At-grade) – Main Street to Arbutus + Arbutus to UBC
- Modified LRT 1 (At-grade) – Arbutus to UBC

8.2.3 Estimate of Costs

Using the above assumptions and cost / km for the guideway components, the plan / profiles from the “Design Workbook 1 – Draft”, dated March 2010 were studied to determine guideway lengths, converting lengths into estimated costs for the three project options.

The cost estimate for RRT (tunnel) from Arbutus to UBC is summarized in *Table 8-15*.

Table 8-15: RRT Arbutus to UBC Cost Summary

	Component	Length	Cost / km	Estimated Cost
RRT	• Tunnel • Stations (4 x $100)	7.1 km -	$160M -	$1,140M $400M
Total RRT (Arbutus to UBC)				**$1,540m**

The cost estimate for the Combo 1 option from Main Street to UBC is summarized in *Table 8-16*.

Table 8-16: Combo 1 (Main Street to UBC) Cost Summary

	Guideway Component	Length	Cost / km (as per *Table 8-14*)	Estimated Cost
Combo 1	• At-Grade • Stations (10 x $5M) (Street Level Stations)	12.0 km -	$70M -	$840M $50M
Total Combo 1 (Main Street to UBC)				**$890M**

The cost estimate for the Modified LRT 1 option from Arbutus Street to UBC is summarized in *Table 8-17.*

Table 8-17: Modified LRT 1 (Arbutus Street to UBC) Cost Summary

	Guideway Component	Length	Cost / km (as per *Table 8-14*)	Estimated Cost
Modified LRT 1	• At-Grade • Stations (5 x $5M)	7.1 km -	$70M -	$500M $25M
Total Modified LRT 1 (Arbutus Street to UBC)				**$525M**

8.2.4 Contingency and Inflation

The Phase 2 Evaluation Report Table 6.2 – Capital Cost Estimate (2010) included “Contingencies” and “2010 Construction Period Inflation” (CPI) where costs during a four-year design / construction period will escalate and require accounting for. Given that concept designs have not yet been developed for the options, suggested contingencies are shown in *Table 8-18*. Preliminary estimates are in 2018 dollars for purposes of comparison. Costs at the actual time of construction would be impacted by inflation between 2018 and construction period. For example, assuming procurement in 2025 with completion in 2030, and 2.5% annual inflation, eventual Year of Expenditure (YOE) dollars would be roughly 25% higher.

Table 8-18: Contingencies

	McElhanney Estimate
Contingencies	30-50%
Construction Period Inflation	10%
Contingency / Inflation	**40-60%**

8.2.5 Total Cost Estimates

The all-inclusive cost estimates for the RRT, Combo 1, and Modified LRT 1 options are detailed in *Table 8-19* using 2018 dollars.

Table 8-19: Comparison of Modified LRT 1, Combo 1 and RRT (YOE 2018$)

	Modified LRT 1 - Arbutus to UBC (7.1km)	Combo 1 - Main-Street Science World to UBC (12.0 km)	RRT – Arbutus to UBC (7.1 km)
Guideway & Stations	$525M	$890M	$1,540M
Maintenance Yard	$350M	$350M	$190M
Subtotal – Construction Cost	**$875M**	**$1,240M**	**$1,730M**
Project Management 12% x Subtotal	$105M	$150M	$210M
Vehicles	$200M	$340M	$200M
Property Acquisition	$50M	$300M	$220M
Subtotal – Soft Costs	**$355M**	**$790M**	**$630M**
Total Base Cost	**$1,230M**	**$2,030M**	**$2,360M**
Contingency / Inflation (40-60%)	$490-740M	$815-1,220M	$940-1,420M
Total (2018) Costs	**$1.7B to $2.0B**	**$2.8B to $3.2B**	**$3.3B to $3.8B**

8.2.6 Summary

The cost estimates developed above are summarized in *Table 8-20*. These estimates should be considered indicative only based on the approach applied to determine these estimates, which is substantially based on the May 1, 2018 Government of BC press release of the BSP and Surrey LRT cost estimates, as well as partially based on the breakdown of costs identified in the 2016 Evergreen Line release and other assumptions as provided. A tunnelled RRT is assumed for this analysis; however, an elevated RRT would have reduced operating and construction costs. To be consistent with the previous analysis, a tunnelled RRT is assumed at this stage.

Only after a concept design has been developed can cost estimates be more reliably determined.

Table 8-20: Comparing Three Options – Modified LRT 1, Combo 1 and RRT

Option			Length	2018 Cost	Cost / km
1	Modified LRT 1	Arbutus to UBC	7.1 km	$1.7B to $2.0B	$240 - 280M / km
2	Combo 1	Main-Street Science World to UBC	12.0 km	$2.8B to $3.2B	$230 - 270M / km
3	RRT	Arbutus to UBC	7.1 km	$3.3B to $3.8B	$460 - 540M / km

DRAFT

9. MODE SHARE TARGETS

This section considers the trade-offs between different technologies and options, taking into account transit mode share targets, capacity and costs and sets out the relative benefits and costs of the Modified LRT 1, RRT and the Combo 1 options, relative to the existing B-Line.

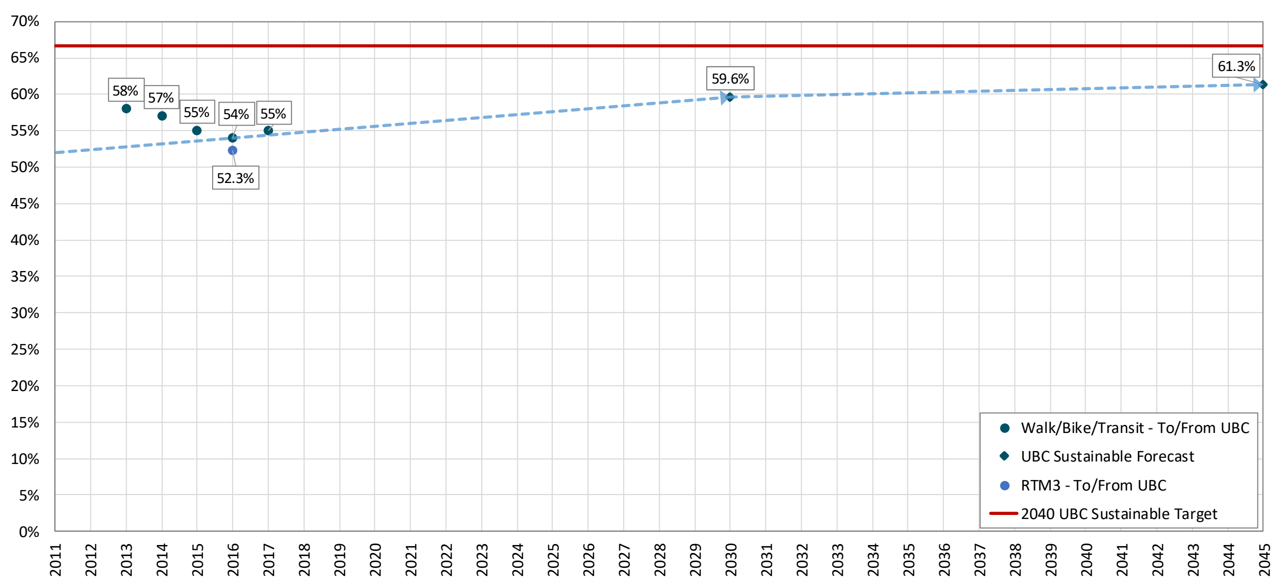
9.1 MEETING MODE SHARE TARGETS

Each of the participating agencies have established long term sustainable mode share targets. An assessment of rapid transit technologies relative to their ability to best support mode share targets for the Metro Vancouver region, City of Vancouver and UBC as set out in their respective plans has been undertaken. Mode share estimates derived from information from traffic counts, travel surveys and scenario analysis in RTM3 has been analyzed and summarized in the following sub sections.

9.1.1 UBC

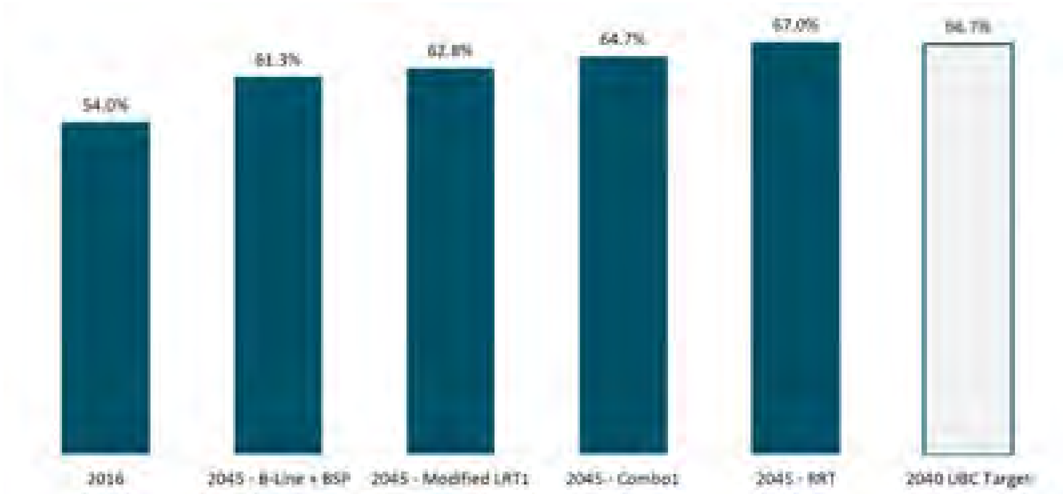
UBC targets are to achieve a two-thirds (66.7 percent) sustainable mode share by 2040 and to maintain 50 percent transit mode share for trips to and from the campus. Based on screenline traffic classification data, the proportion of transit trips to and from UBC has held steady at 52 percent between 2015 and 2017. The proportion of sustainable (transit, walk, and bike) trips to and from UBC was around 54 percent in 2016 and 55 percent in 2017. Application of the RTM3 trendline indicates that this will increase to 59.6 percent in 2030 and to 61.3 percent in 2045; short of UBC's target of 66.7 percent as shown in *Figure 9-1*. There are several factors contributing to this increase sustainable mode share trend. UBC has implemented the U-Pass program in partnership with TransLink since 2003 providing a subsidized transit pass for university students. This, along with restricted parking supply and increased parking costs, has resulted in high transit ridership for students commuting to and from campus.

Figure 9-1: UBC Sustainable Mode Share: BAU Trendline



The choice of transit technology for the rapid transit extension to UBC will affect mode share for trips to and from UBC, as shown in *Exhibit 9-1* which show the sustainable mode share for trips to and from campus respectively. Based on ridership forecasts, all technology options will support the growth in transit ridership. RRT is the only alternative that enables UBC to meet its 2040 sustainable mode share target.

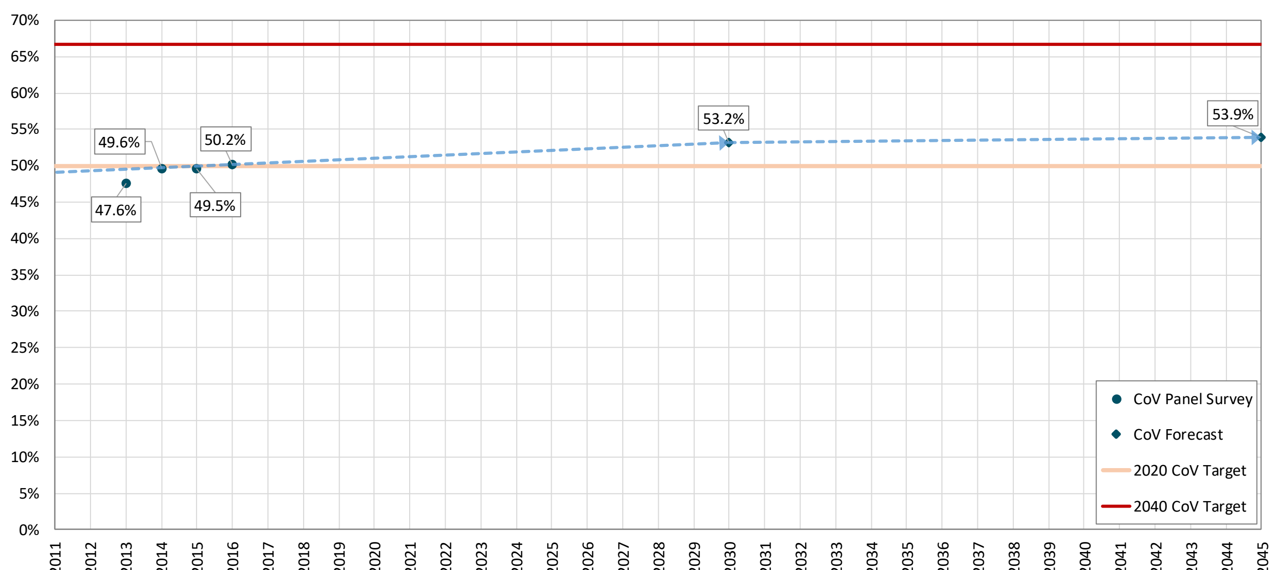
Exhibit 9-1: UBC Sustainable Mode Shares



9.1.2 City of Vancouver

City of Vancouver targets are to achieve a 50 percent sustainable mode share by 2020 and a two-thirds (66.7 percent) sustainable mode share by 2040. Based on City of Vancouver Panel Survey data, the City's sustainable mode share has steadily increased from 47.6 percent in 2013 to 50.2 percent in 2016. Longer term application of the RTM3 trendline to 2045 under a B-Line (BAU) scenario indicates that the City is forecast to fall short of its sustainable mode share targets, with sustainable modes attaining a total of 53.2 percent of resident trips in 2030 and 53.9 percent of resident trips in 2045 as shown in *Figure 9-2*.

Figure 9-2: City of Vancouver Sustainable Mode Share: BAU Trendline



The choice of transit technology for the rapid transit extension to UBC will impact the City's mode share, with all three technology options likely to increase sustainable mode share to approximately 54 percent in 2045. Each of the options trends towards the City's sustainable mode share target although significantly short of the 2040 target of 66.7 percent as shown *Exhibit 9-2*. Further investments in transit and sustainable transportation infrastructure will be required if the City is to meet its mode share targets.

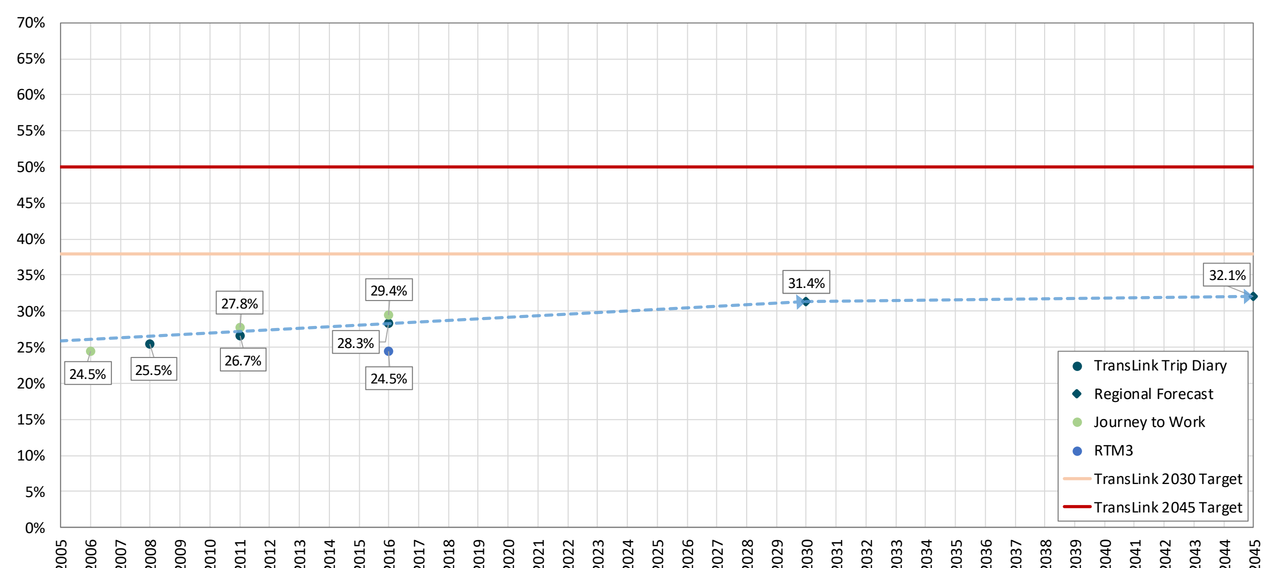
Exhibit 9-2: Sustainable Mode Share for City of Vancouver

9.1.3 Metro Vancouver

TransLink targets to achieve a 38 percent sustainable mode share by 2030 and a 50 percent sustainable mode share across Metro Vancouver by 2045. The 2011 Trip Diary indicates a sustainable mode share of 26.7 percent for Metro Vancouver, while the census journey to work data indicate a 27.8 percent sustainable mode share for the same year. The 2016 census journey to work data indicate a 29.4% sustainable mode share.

Application of the RTM3 trendline to 2045 to these data indicates that Metro Vancouver will reach a 31.4 percent sustainable mode share by 2030 (under the BAU scenario) and 32.1 percent in 2045, well short of the 38 percent and 50 percent sustainable mode share targets (*Figure 9-3*).

Figure 9-3: Metro Vancouver Sustainable Mode Share BAU Trendline

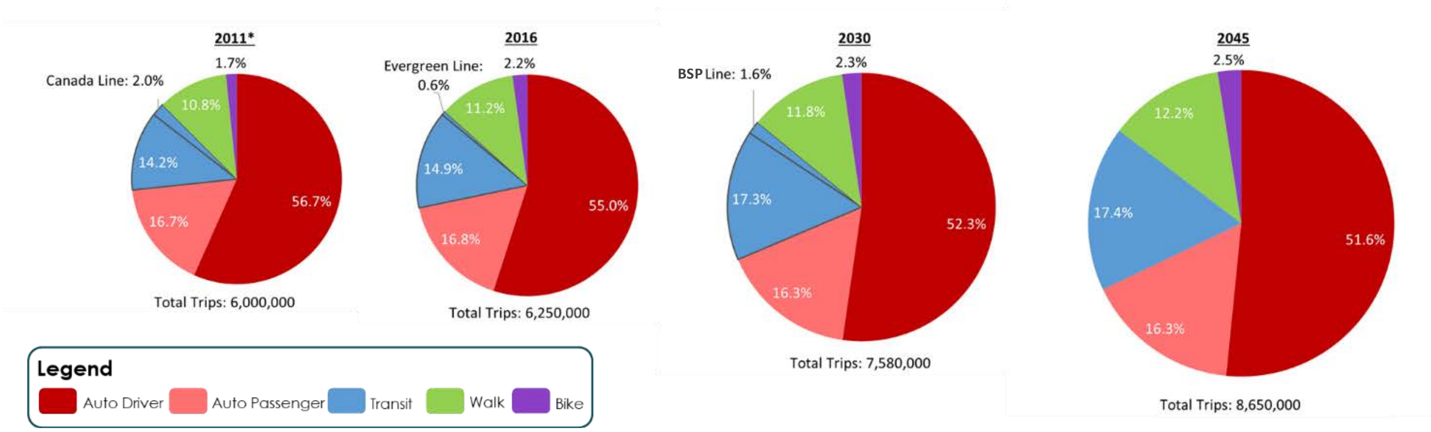


The choice of transit technology for the rapid transit extension to UBC will only marginally impact overall mode share for Metro Vancouver as a whole, shown in *Exhibit 9-3*. Rapid transit investment contributes approximately 1 to 2 percent of the regional mode share as shown in *Exhibit 9-4*, with Canada Line ridership contributing approximately 2% and

Evergreen Line contributing approximately 0.6% to the regional mode share. Note that this includes previous ridership on both the 98 and 97 B-Line services so the actual incremental increase is somewhat lower. BSP is predicted to contribute approximately 1.6% to the regional mode share in 2030 after it is completed.

Exhibit 9-3: Sustainable Mode Share for Metro Vancouver

Exhibit 9-4: Impacts of Rapid Transit on Overall Sustainable Mode Share for Metro Vancouver



** 2011 data based on Trip Diary, all other years based on RTM3.*

9.1.4 Implications

Based on the forecasting undertaken, the Combo 1 and RRT options will help move the sustainable mode share closer to the targets for each of the agencies, but rapid transit on the Broadway/10th Ave corridor alone will not achieve the long-term sustainable mode share targets. Additional transportation investment and travel demand management will be required to achieve this. Note that these scenarios do not include any form of mobility pricing which, if implemented, would incentivize more people to use transit.

Of the options, Combo 1 is likely to increase sustainable mode share in the City of Vancouver to 54.2 percent in 2045 (from 50.2 percent in 2016), supporting a closer match to the City's sustainable mode share targets than other options (although still short of the 2040 target of 66.7 percent). The model does not include transit supportive land use changes, mobility pricing and others that would help the City to achieve its sustainable mode share target. Based on ridership forecasts, all technology options will support growth in transit ridership, however RRT is the only alternative that supports UBC's 2040 sustainable mode share target.

The choice of transit technology for the rapid transit extension to UBC will only marginally impact overall mode share for Metro Vancouver as a whole due to rapid transit investment contributing just 1 to 2 percent of the regional mode share. Further, this corridor along with the parallel corridors already carry a substantial level of transit ridership and any improvements to speed and capacity along the Broadway/10th Ave corridor will divert trips from the other corridors.

PART 2: ADDITIONAL REVIEW AND ANALYSIS

10. REVIEW OF ADDITIONAL LRT SCENARIOS

This section provides a review and assessment of additional LRT scenarios that arose during Part 1 project discussions. The rationale for these scenarios is to provide additional capacity for parallel corridors serving UBC since the one LRT line along the Broadway/10th Ave corridor does not provide sufficient capacity to meet future ridership demand. In order to meet future potential ridership demand a second LRT line along the 41st Ave corridor extending from UBC to the Oakridge-41st Ave (Canada Line) and Metrotown (Expo Line) stations was assessed in terms of its impacts to ridership, capacity and project cost.

10.1 ALIGNMENT & OPERATING ASSUMPTIONS

In order to provide a second rapid transit route to serve UBC, a review of logical corridor options that meets regional travel needs was conducted. The 41st Ave corridor was the most logical alternative as it currently provides an efficient connection between the Expo Line at Joyce Station to UBC with Route 41/43 service. A terminus at Metrotown rather than Joyce Station was deemed to be the more regionally significant connection. Each of the alternate LRT scenarios is assumed to operate with a four-minute headway and an approximate 25 km/h average operating speed. In terms of the Marine Dr, 41st Ave and Kingsway corridor cross sections, they are assumed to be reduced by two lanes for four lane segments while still maintaining a minimum two-lane cross section for the entire corridor. The road right-of-way through Kerrisdale is constrained and will require removal of street parking to accommodate two general purpose traffic lanes and two LRT tracks.

Figure 10-1 and *Figure 10-2* illustrate the proposed alignments for the Modified LRT 1 and Combo 1 options assuming a hypothetical second LRT corridor with a terminus at Oakridge-41st Ave station. *Figure 10-3* and *Figure 10-4* display the LRT options with the terminating station at Metrotown. As seen in the figure, these routes replicate much of the existing Route 43 bus route. A feasible alignment along Kingsway and then cutting through Central Park along the Expo corridor was determined. This alignment is assumed to integrate directly with the Modified LRT 1 and Combo 1 alternatives with no transfer requirement at the UBC campus. In other words, this option is provided as an extension to the other two LRT scenarios.

Figure 10-1: LRT Network 1 – Modified LRT 1 + 41st LRT to Canada Line Oakridge Station Alternative

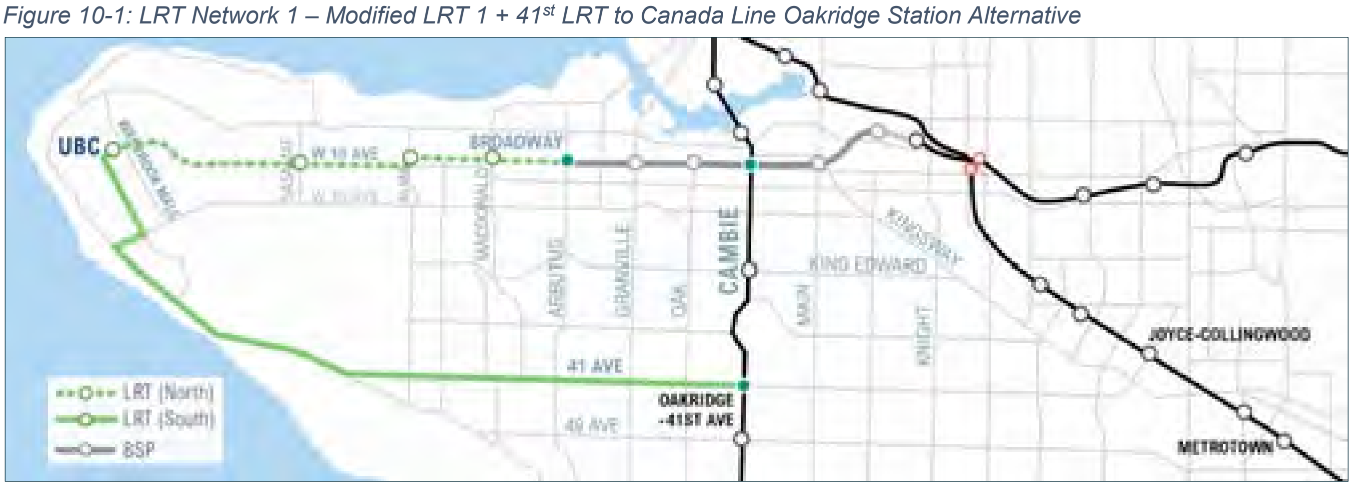


Figure 10-2: LRT Network 2 – Combo 1 + 41st LRT to Canada Line Oakridge Station Alternative

Figure 10-3: LRT Network 3 – Modified LRT 1 + 41st LRT to Expo Line Metrotown Station Alternative

Figure 10-4: LRT Network 4 – Combo 1 + 41st LRT to Expo Line Metrotown Station Alternative

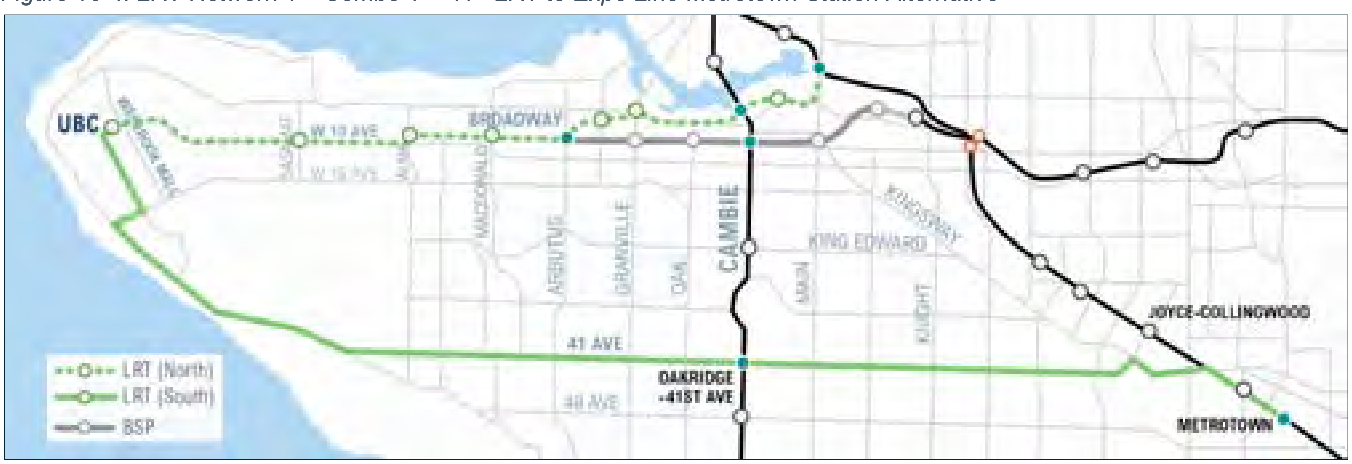


Table 10-1 provides a summary of the operating assumptions including length of rapid transit track, number of stops and other operating parameters for the four LRT alternatives being considered. With two potential LRT corridors, the total LRT capacity to UBC would double from 7,200 to 14,400 pphpd.

Table 10-1: Rapid Transit Scenario Operating Assumptions

Alternatives	Routes	Route Length (km)	Stops	Headway (mins)	Operating Speed (km/h)	Practical / Theoretical Capacities (pphpd)
LRT Network 1 – Modified LRT 1 + 41st LRT to Canada Line Oakridge Station	UBC – Arbutus UBC – Oakridge-41st	7.1 12.2	5 7	4 4	25 25	6,120 / 7,200 6,120 / 7,200
LRT Network 2 – Combo 1 + 41st LRT to Canada Line Oakridge Station	UBC – Main St-Science World UBC – Oakridge-41st	12.0 12.2	10 7	4 4	25 25	6,120 / 7,200 6,120 / 7,200
LRT Network 3 – Modified LRT 1 + 41st LRT to Expo Line Metrotown Station	UBC – Arbutus UBC – Metrotown	7.1 20.7	5 14	4 4	25 25	6,120 / 7,200 6,120 / 7,200
LRT Network 4 – Combo 1 + 41st LRT to Expo Line Metrotown Station	UBC – Main St-Science World UBC – Metrotown	12.0 20.7	10 14	4 4	25 25	6,120 / 7,200 6,120 / 7,200

Table 10-2 provides the end-to-end run times between UBC and the Metrotown Station for the four alternatives being considered with B-Line service provided between Oakridge Station and Joyce Station for the LRT extension to Oakridge Station.

Table 10-2: End-to-End Run Times Between Joyce-Collingwood / Metrotown and UBC

	B-Line (Joyce – Oakridge) + LRT (Oakridge – UBC)		LRT (Metrotown – UBC)	
	LRT Network 1	LRT Network 2	LRT Network 3	LRT Network 4
In-Vehicle Time (mins)	59	59	50	50
End-to-End Time Including Walk Access and Wait Times (mins)	63	63	52	52

10.2 CAPACITY & RIDERSHIP OUTCOMES

These LRT alternatives were coded in the Regional Transportation Model and used to estimate peak directional demand and the line profiles. *Figure 10-5* to *Figure 10-8* provide the ridership and line profiles for these extensions of the Modified LRT 1 and Combo 1 alternatives to Oakridge and Metrotown for the 2045 AM peak hour westbound direction. The following provides a summary of ridership for each alternative:

- **LRT Network 1** – **Modified LRT 1 with 41st LRT to Oakridge-41st Ave Station**: For this alternative, there are two transfers for trips to UBC from the Expo Line; one from the Expo Line to the 43 B-Line and another to board the LRT at Oakridge-41st Station. There are a low number of boardings for stations between Joyce-Collingwood and Oakridge-41st which sees over 2,700 boardings. Boarding activity for stations to the west build ridership to a maximum of over 3,400 passengers per hour, well below LRT's theoretical capacity of 7,200 pphpd.

- **LRT Network 2** – **Combo 1 with 41st LRT to Oakridge-41st Ave Station**: This alternative has a very similar load profile to the LRT Network 1 alternative, however with overall reduced ridership. The LRT Network 2 alternative along the 2nd Ave alignment to Science World competes for the same ridership as those along 41st Ave. The difference is that the LRT Network 2 alignment provides a transfer free trip between Main St-Science World to UBC and is a more attractive alternative for many users.
- **LRT Network 3** – **Modified LRT 1 with 41st LRT to Metrotown Station**: With only one transfer from the Expo Line at Metrotown and a faster operating speed, this alternative attracts much higher ridership compared to the alternatives where LRT terminates at Oakridge. There are over 3,100 boardings at Metrotown and a steady increase of ridership to Oakridge-41st where there are over 1,100 boardings and over 1,000 alightings. This line then carries approximately 5,300 passengers to UBC. This alternative carries the highest peak directional load to UBC which is still well below LRT's ultimate capacity of 7,200 pphpd.
- **LRT Network 4** – **Combo 1 with 41st LRT to Metrotown Station**: The line profile for this alternative is very similar to that of the LRT Network 3 option, however there is a drop in the peak directional volume to approximately 4,400 pphpd. This is due to the LRT Network 4 alternative providing a connection between Main St-Science World that competes for the same passengers as the alignment along 41st Ave.

Figure 10-9 to *Figure 10-12* show the transit volume difference plots for the alternatives assuming that they are built cumulatively in the following order:

1. First segment is built from Arbutus to UBC. This segment draws transit ridership from the 4th Ave, 16th Ave, King Edward and 41st Ave corridors to Broadway/10th Ave. Because of an improvement in speed and capacity over the existing 99 B-Line, there are additional passengers that utilize the BSP to Arbutus.
2. Second segment extends the line from Arbutus to Main St-Science World. This segment competes directly with BSP and provides a transfer-free alternative for passengers travelling through to UBC. This also results in increased ridership on the Expo Line adding ridership to an already congested service. It also results in increased ridership on the LRT segment from Arbutus to UBC.
3. Third segment extends the line from UBC to Oakridge-41st. This segment draws a small amount of ridership from the Broadway/10th Ave corridor as it provides a secondary East-West service from Canada Line to UBC.
4. Fourth segment extends the line from Oakridge-41st to Metrotown. This final segment draws a significant amount of ridership from the Combo 1 Alternative route as it provides an upstream connection to UBC from the Expo Line. It generally attracts more ridership to the system as it provides a complete second LRT corridor to UBC.

In each of these alternatives, there is an increase in transit service but also a reduction in road network capacity. *Figure 10-13* shows the auto volume difference plot for the 2045 AM peak hour for the completed LRT network. This plot shows a reduction in auto volumes along Broadway/10th Ave and a more significant drop along 41st Ave and Kingsway. As mentioned previously, the LRT track will require two lanes of road space which will increase auto travel times and make transit even more attractive for trips travelling along these corridors. In southern Vancouver, there are 10 lanes[43] of arterial capacity east-west between 41st Ave and Marine Dr. With two lanes lost to LRT on 41st Ave, this results in a 20% reduction in east-west arterial road network capacity in this part of Vancouver.

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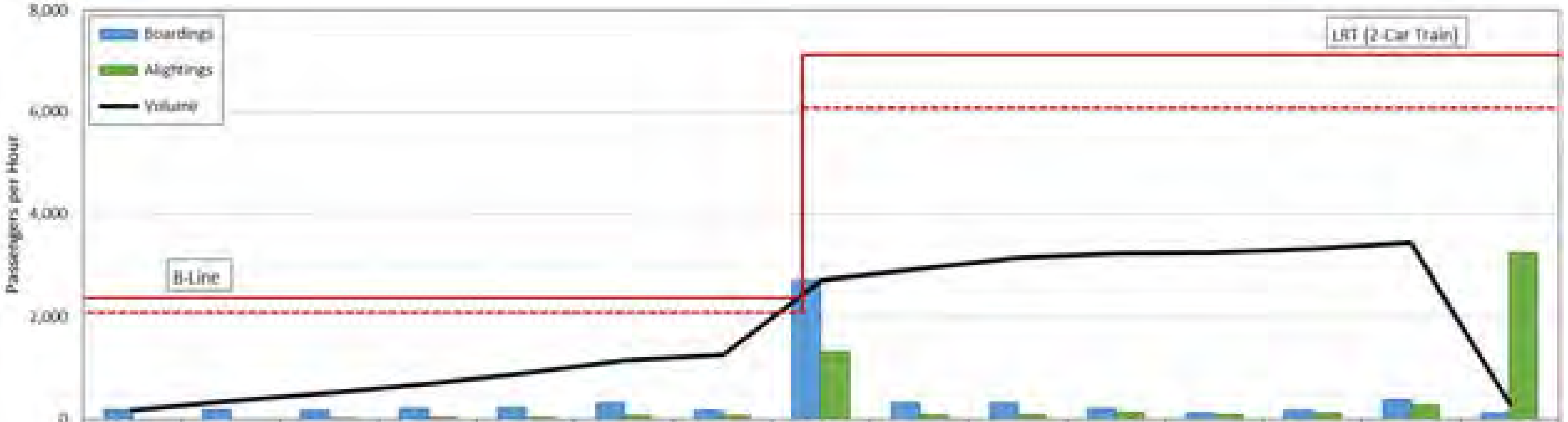
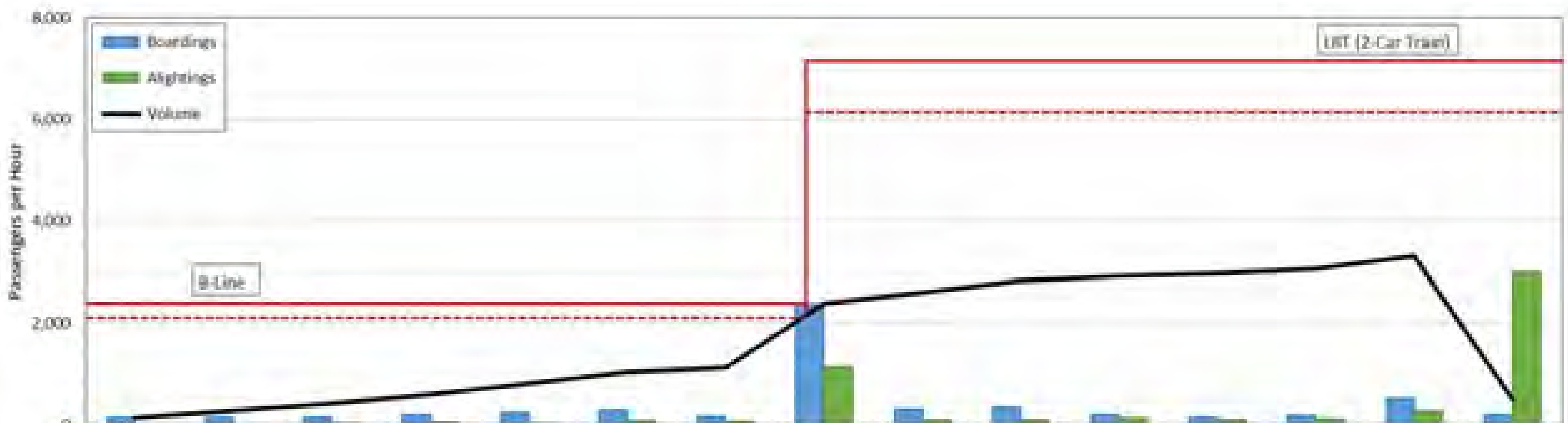
[43] Four lane cross section on 41st Ave, two lane cross section on 49th Ave and four lane cross section on Marine Dr.

Figure 10-5: Line Profile for 2045 AM Peak Westbound Ridership on LRT Network 1 from Joyce-Collingwood to UBC



	Joyce-Collingwood	Kingsway	Clarendon	Victoria	Knight	Fraser	Main	Oakridge-41st	Oak	Granville	West Blvd	Carnarvon	Dunbar	Stadium	UBC
Boardings	180	180	170	200	230	320	170	2,710	310	310	210	120	170	380	110
Alightings	0	0	10	10	20	70	60	1,327	90	90	130	90	110	270	3,240
Volume	180	350	520	690	900	1,150	1,260	2,710	2,930	3,140	3,230	3,250	3,320	3,430	300

Figure 10-6: Line Profile for 2045 AM Peak Westbound Ridership on LRT Network 2 from Joyce-Collingwood to UBC

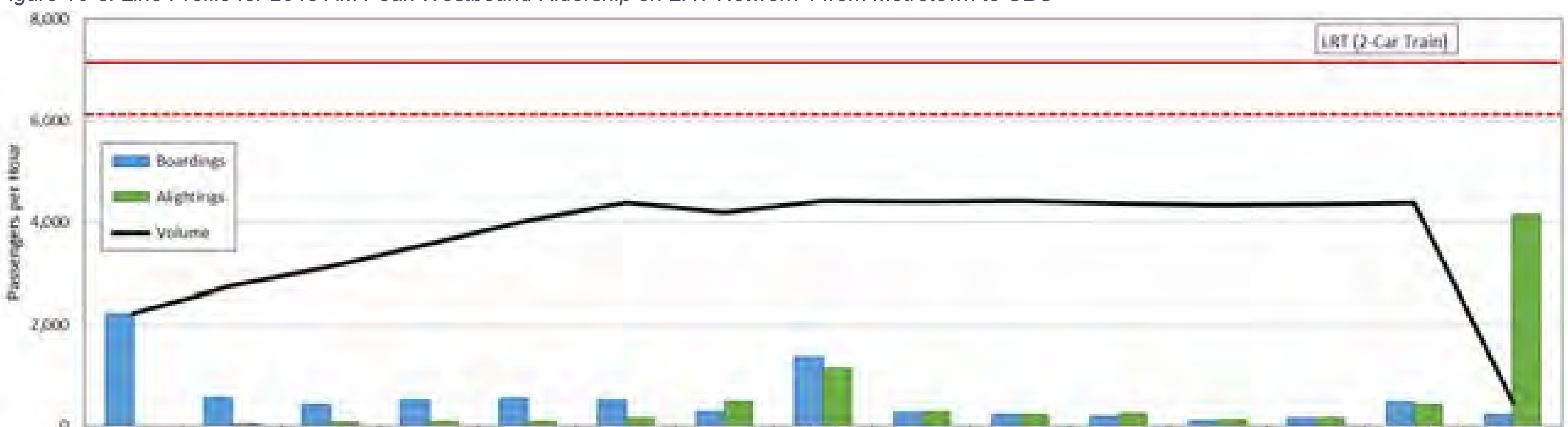


	Joyce-Collingwood	Kingsway	Clarendon	Victoria	Knight	Fraser	Main	Oakridge-41st	Oak	Granville	West Blvd	Carnarvon	Dunbar	Stadium	UBC
Boardings	140	150	150	200	230	290	170	2,380	300	330	200	150	180	520	190
Alightings	0	0	10	30	20	70	60	1,130	90	90	120	90	100	270	3,000
Volume	140	280	420	590	800	1,030	1,130	2,380	2,590	2,830	2,910	2,970	3,050	3,300	490

Figure 10-7: Line Profile for 2045 AM Peak Westbound Ridership on LRT Network 3 from Metrotown to UBC

	Metrotown	Kingsway	Clarendon	Victoria	Knight	Fraser	Main	Oakridge-41st	Oak	Granville	West Blvd	Carnarvon	Dunbar	Thunderbird Stadium	UBC
Boardings	3,130	670	440	490	530	520	250	1,150	270	200	200	90	140	340	150
Alightings	0	30	50	70	80	160	320	1,080	250	210	230	130	150	380	5,170
Volume	3,130	3,770	4,160	4,580	5,030	5,390	5,330	5,400	5,410	5,410	5,380	5,340	5,330	5,300	270

Figure 10-8: Line Profile for 2045 AM Peak Westbound Ridership on LRT Network 4 from Metrotown to UBC



	Metrotown	Kingsway	Clarendon	Victoria	Knight	Fraser	Main	Oakridge-41st	Oak	Granville	West Blvd	Carnarvon	Dunbar	Thunderbird Stadium	UBC
Boardings	2,220	560	430	520	550	520	280	1,360	270	230	190	110	150	460	220
Alightings	0	40	60	80	80	160	480	1,130	280	220	240	130	150	420	4,140
Volume	2,220	2,750	3,130	3,560	4,030	4,390	4,180	4,410	4,400	4,410	4,360	4,330	4,340	4,380	460

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Figure 10-9: 2045 AM Peak Transit Volume Difference Plot for First Segment from Arbutus to UBC

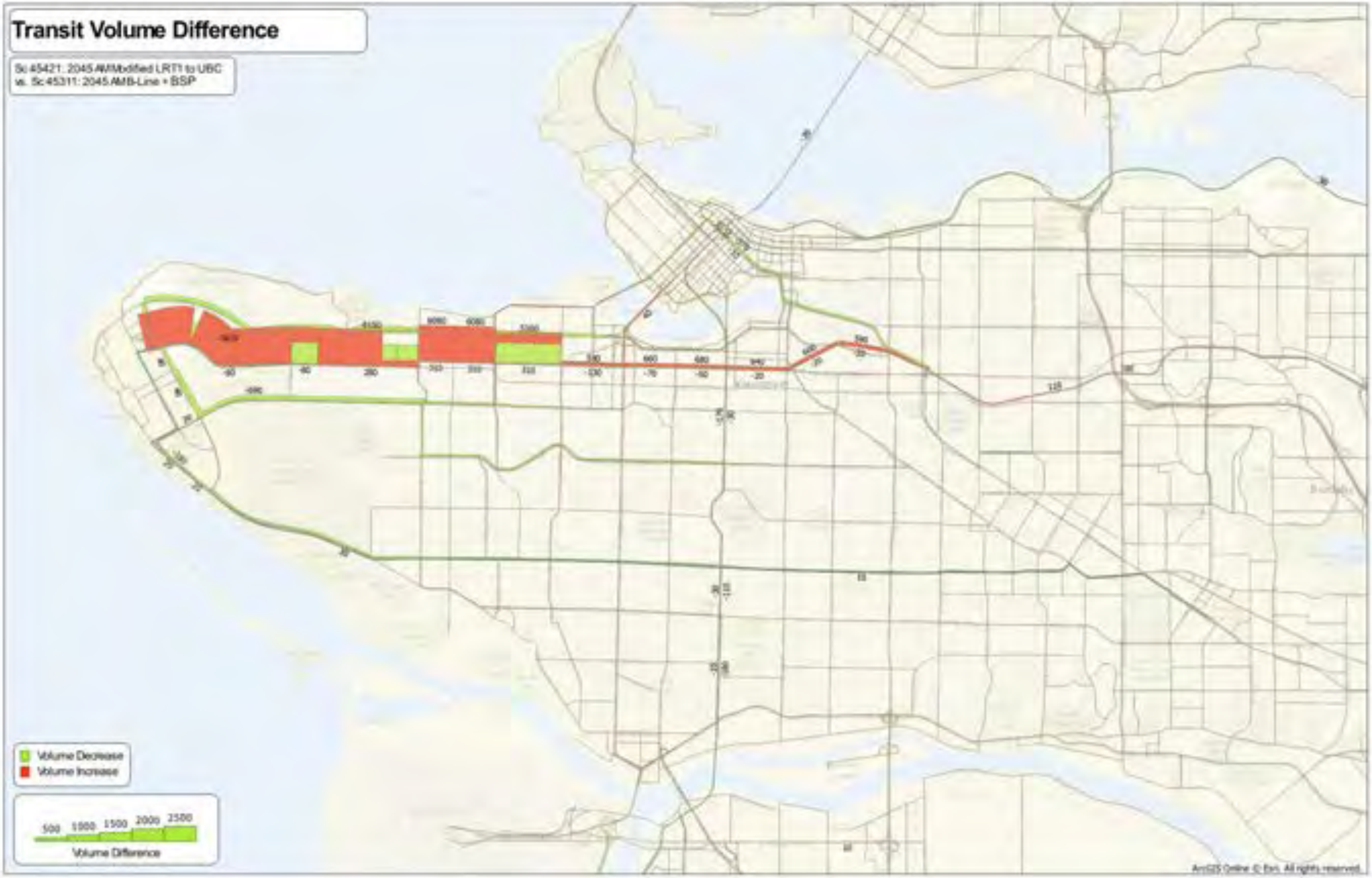


Figure 10-10: 2045 AM Peak Transit Volume Difference Plot for Second Segment from Arbutus to Main Street-Science World

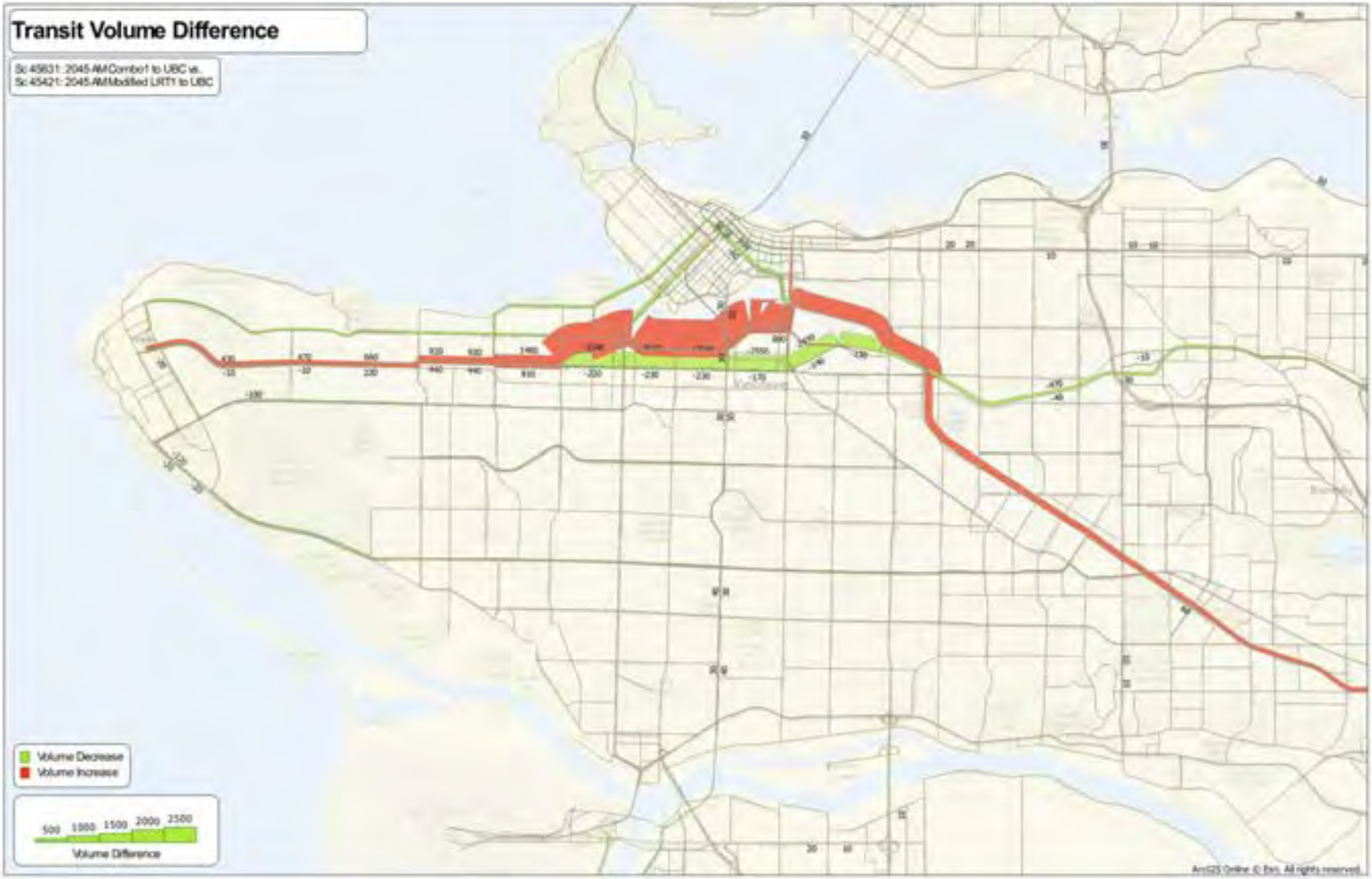


Figure 10-11: 2045 AM Peak Transit Volume Difference Plot for Second Segment from UBC to Oakridge-41st

Figure 10-12: 2045 AM Peak Transit Volume Difference Plot for Second Segment from Oakridge-41st to Metrotown

Figure 10-13: 2045 AM Peak Auto Volume Difference Plot for Complete LRT Network from Main Street-Science World to UBC to Metrotown

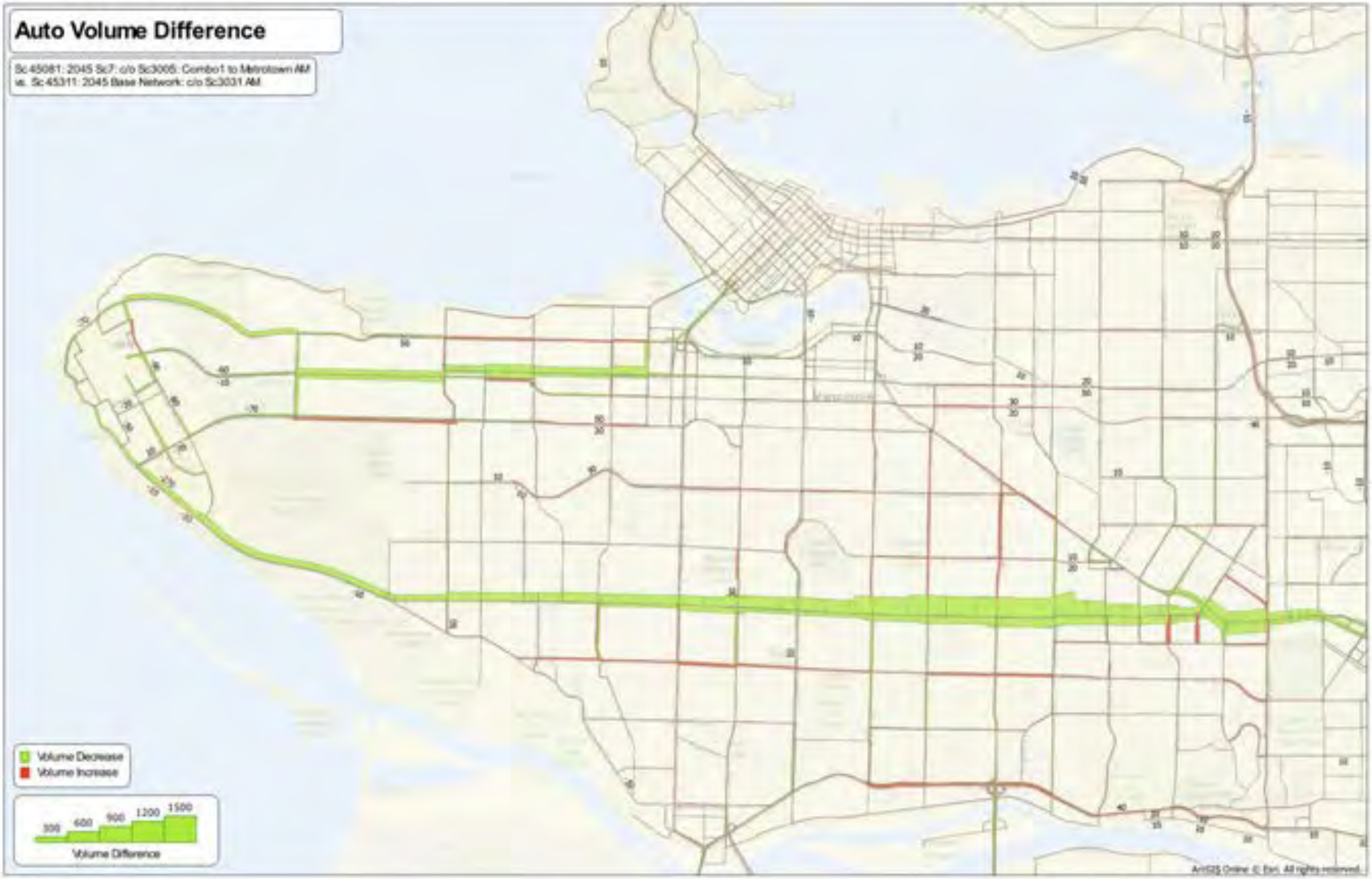
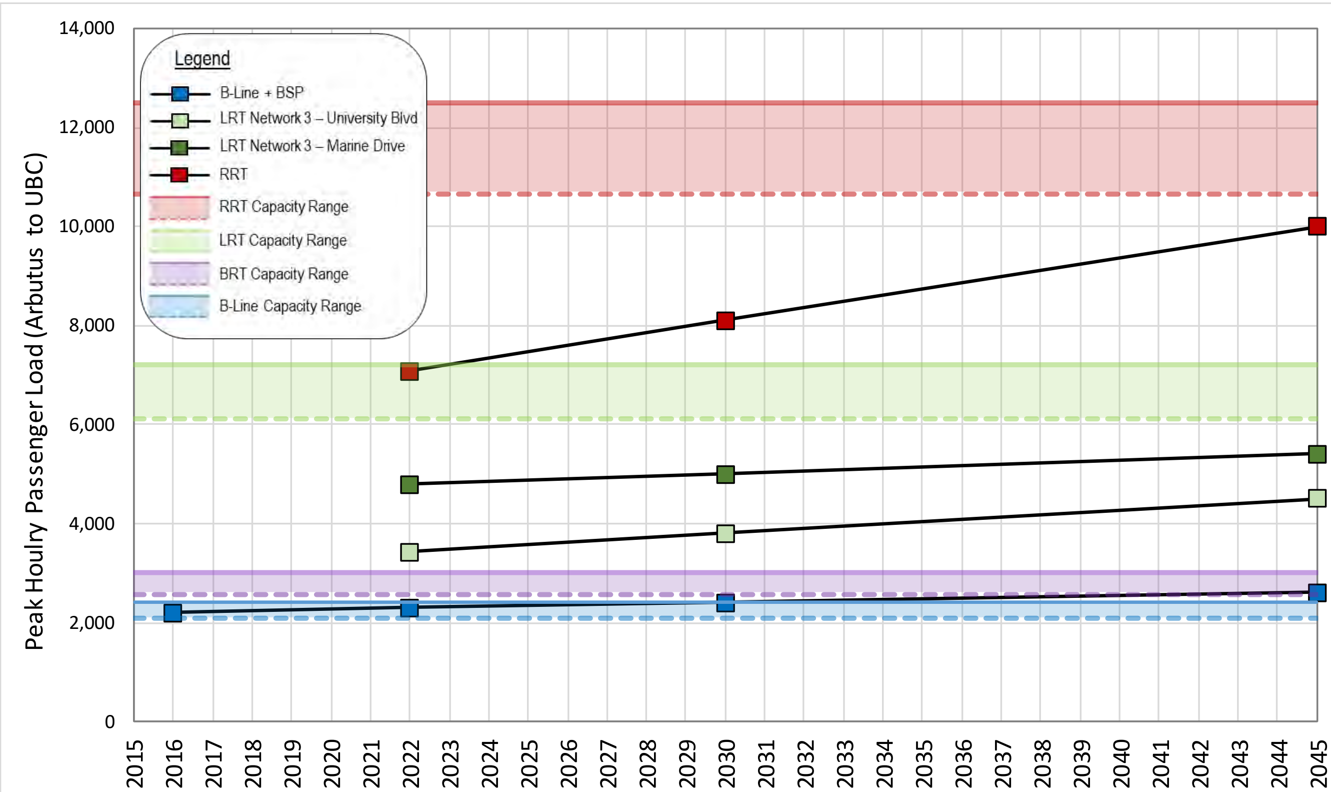


Figure 10-14 shows the peak directional ridership demand for technology alternatives combined with the Modified LRT 1 alternative measured at the UBC screenline. The capacity range for each technology is based on the theoretical capacity and practical capacity which is generally 85% of theoretical capacity.

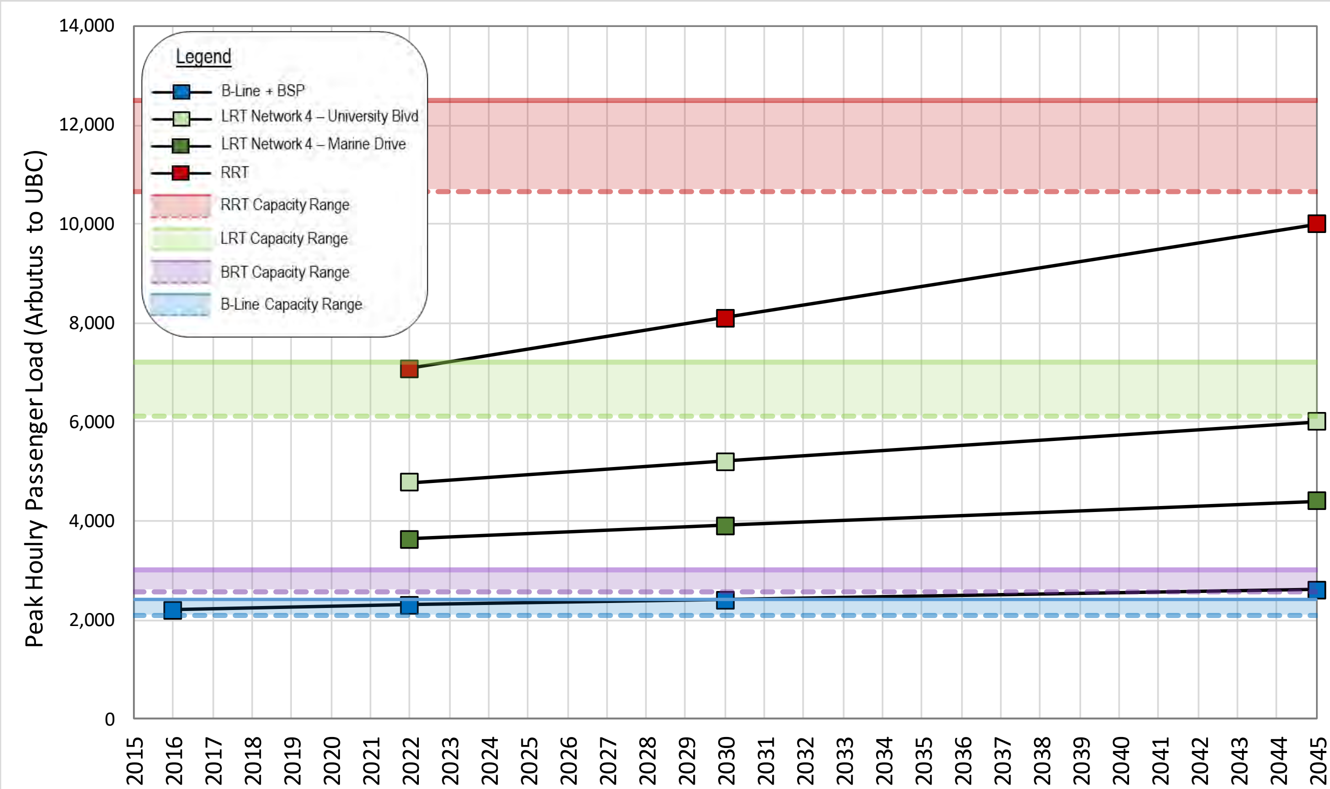
With just the Modified LRT 1 on its own, it generally operated below practical capacity in the 2045 AM peak hour horizon. With the extension of LRT to Metrotown, the twin LRT lines measured at the UBC screenline operate well within the practical capacity of LRT. In terms of capacity, generally the twin LRT lines (combined capacity of 14,400 pphpd) are equivalent to one RRT[44] line serving UBC, though transit user benefits are lower due to slower speeds. *Figure 10-15* shows the same figure for the Combo 1 alternative combined with the extension of LRT to Oakridge. With just the Combo 1 alternative, the LRT line operated above its practical capacity. With the extension of LRT to Oakridge, the twin lines operate well within practical capacity in 2045. Similar to the Modified LRT 1 alternative, the two LRT lines serving UBC provide equivalent level of capacity to one RRT line.

Figure 10-14: Peak Directional Weekday Ridership for Technology Alternatives Combined with LRT Network 3 Option



[44] *RRT capacity can be expanded to 26,000 pphpd.*

Figure 10-15: Peak Directional Weekday Ridership for Technology Alternatives Combined with LRT Network 4 Option



In order to further understand ridership implications of these alternatives, all of the technology alternatives were measured against each other. *Figure 10-16* provides a summary of 2045 AM peak westbound ridership at the UBC screenline for all of the technology and route alternatives investigated to date. This figure also provides a breakdown of ridership carried by the alternative services/technologies available. In the first set of original scenarios, RRT carries the highest level of ridership, much of which is diverted from ridership on parallel routes serving UBC. Of the LRT Network options, LRT Network 4 carries the highest level of ridership. The increased ridership measured at Marine Dr from each of the extended LRT scenarios comes from diversion from other bus routes and the Modified LRT 1 or Combo 1 alternatives.

Figure 10-17 provides the overall impact to regional ridership which varies from a net gain of 0.3% to 2.6%. In all cases, the alternatives that include Combo 1 have the highest level of uplift to regional ridership because it provides the most geographic coverage in terms of line length and station catchment area. Similarly, the LRT Network options to Oakridge and Metrotown provide additional uplift to regional ridership because of the extensive increase in line length and station catchment area. The LRT options also have an uplift to ridership as road space is reduced to accommodate at-grade rail operations which disincentivizes auto use. A scenario with RRT to UBC and LRT on 41st Avenue was not modelled.

Table 10-3 provides a summary table for the additional LRT Network scenarios that were analyzed including key metrics such as travel time, peak load, capacity and construction costs. The two LRT corridors provide a combined theoretical capacity of 14,400 pphpd, representing a 15% increase over the RRT, which has an assumed service capacity to accommodate 12,500 pphpd. However, the ultimate capacity of the RRT can be expanded up to 26,000 pphpd as demand increases, whereas the LRT is not expandable beyond 7,200 pphpd per corridor. In terms of peak directional load, the RRT carries 10,000 pphpd, while the LRT Network scenarios carry a combined peak load ranging from 8,900 to 10,400 pphpd, indicating similar levels of peak passenger loads between the two transit technologies.

The cost of the LRT system varies depending on the level of network coverage. The LRT Network 1 ranges from $3.7B to $4.3B, costing 12% more than the RRT, while carrying a peak load that is 10% lower. The most extensive network option (LRT Network 4) ranges from $6.2B to $7.1B, costing almost 90% more than the RRT, while carrying only 4%

more at its peak load. Although the LRT Network options can provide similar levels of capacity and peak load as the RRT, the construction costs associated with building the two LRT corridors are significantly higher than the RRT.

Figure 10-16: 2045 AM Peak Westbound Ridership at UBC Screenline

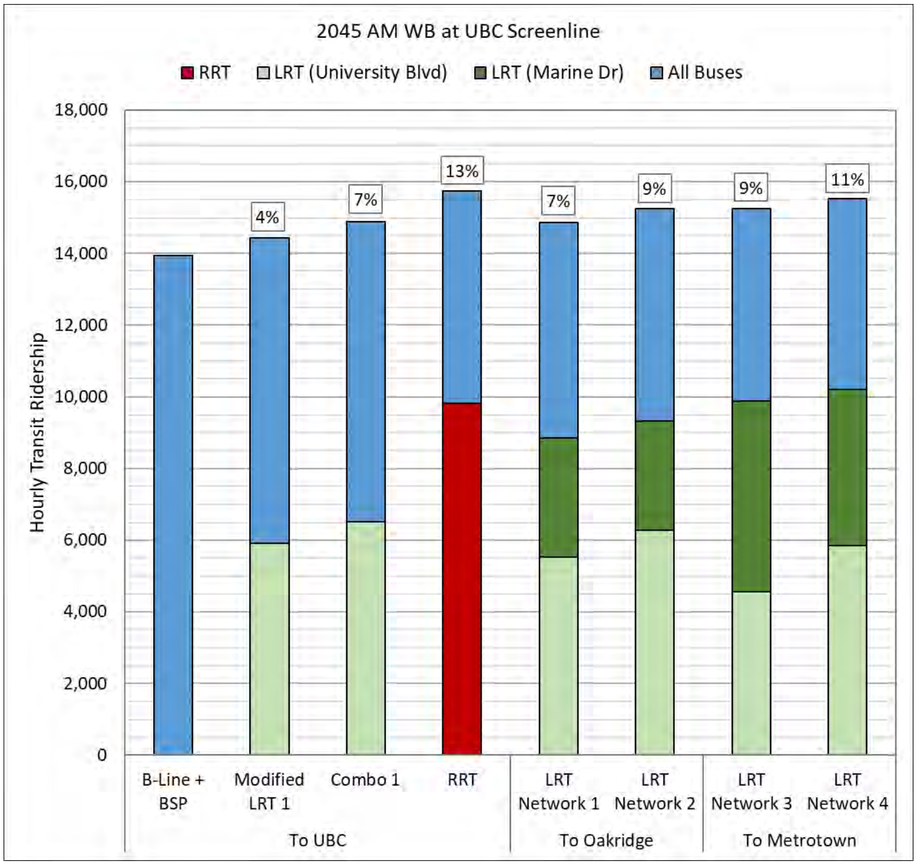


Figure 10-17: 2045 Daily Regional Transit Trips

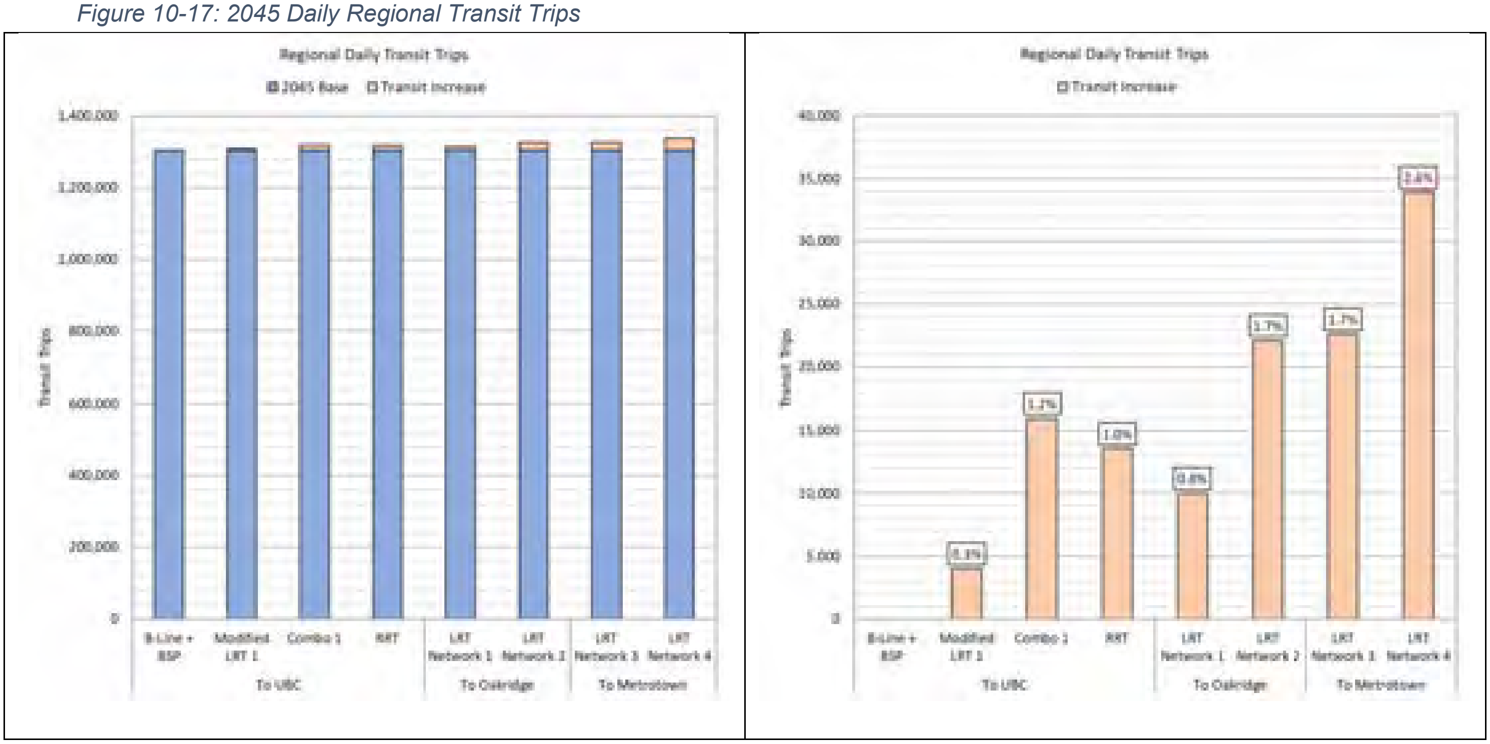


Table 10-3: Trade-off Summary Table for Additional LRT Scenarios

	LRT Network 1	LRT Network 2	LRT Network 3	LRT Network 4
	Modified LRT 1 + LRT extension to Oakridge-41st & B-Line to Joyce-Collingwood	Combo 1 + LRT extension to Oakridge-41st & B-Line to Joyce-Collingwood	Modified LRT 1 + LRT extension to Metrotown	Combo 1 + LRT extension to Metrotown
ROUTE LENGTH (km) LRT Track Length (km) Bus Route Length (km) Total Length (km)	 19.3 km 6.6 km 25.9 km	 24.2 km 6.6 km 30.8 km	 27.9 km - 27.9 km	 32.8 km - 32.8 km
NUMBER OF STOPS	12	17	19	24
TRANSIT TRAVEL TIME In-Vehicle Time (mins) End-to-End Time Including Walk Access and Wait Times (mins)	 77 81	 87 91	 67 69	 78 80
LRT CAPACITY PER CORRIDOR Practical Capacity Theoretical Capacity Max Build-Out / Expansion Capacity	 6,120 7,200 7,200	 6,120 7,200 7,200	 6,120 7,200 7,200	 6,120 7,200 7,200
2045 PEAK LOAD (% OF PRACTICAL CAPACITY) University Blvd SW Marine Dr Combined	 5,500 (90%) 3,400 (56%) 8,900 (73%)	 6,500 (106%) 3,300 (54%) 9,800 (80%)	 4,500 (74%) 5,400 (88%) 9,900 (81%)	 6,000 (98%) 4,400 (72%) 10,400 (85%)
PRELIMINARY ESTIMATED COST Based on Surrey LRT per km costs (Includes 40-60% contingency) LRT (North Corridor) LRT (South Corridor) Total	 $1.7 to $2.0 B $2.0 to $2.3 B $3.7 to $4.3 B	 $2.8 to $3.2 B $2.0 to $2.3 B $4.8 to $5.5 B	 $1.7 to $2.0 B $3.4 to $3.9 B $5.1 to $5.9 B	 $2.8 to $3.2 B $3.4 to $3.9 B $6.2 to $7.1 B

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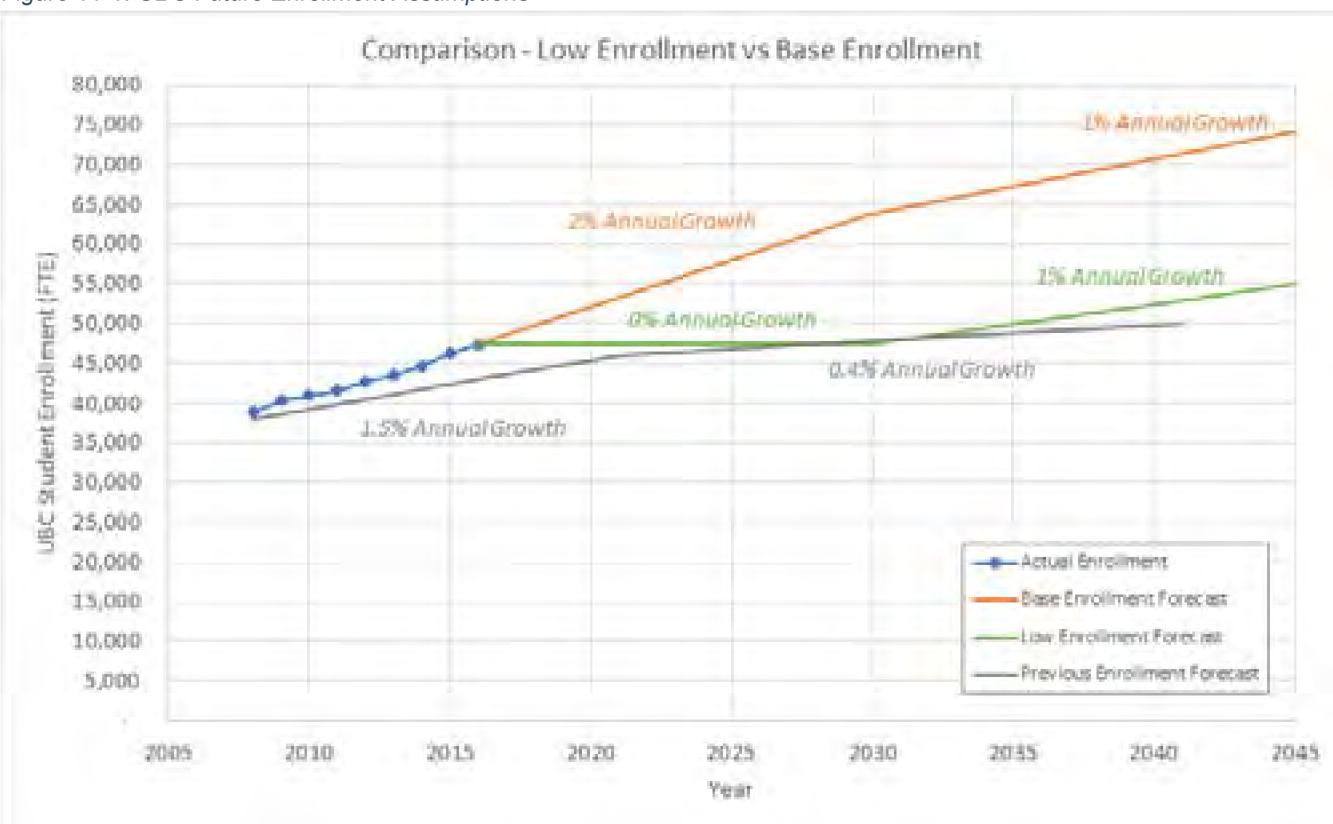
11. REVIEW OF ALTERNATE UBC ENROLLMENT SCENARIO

11.1 ALTERNATE ENROLLMENT ASSUMPTION

A revised enrollment assumption at the UBC campus was analyzed as a sensitivity scenario to better understand ridership uncertainty and impacts to rapid transit vehicle utilization and capacity. *Figure 11-1* below shows historical enrollment which was growing at 2.6% per annum between 2008 and 2017 and the current future assumption to 2030 and 2045 which assumed 2% annual growth to 2030 and 1% annual growth to 2045. The low enrollment forecast assumes zero growth between today and 2030 and then 1% annual growth from 2030 to 2045. The lower enrollment scenario is 26% lower in the 2030 and 2045 horizons. Superimposed on this chart are the previous enrollment forecasts that were assumed in the Phase 2 Evaluation in 2012 which resulted in even lower ridership forecasts to UBC.

Figure 11-1: UBC Future Enrollment Assumptions



11.2 REVISED RIDERSHIP FORECASTS

With the adjusted enrollment forecasts, a revised set of ridership forecasts for the RRT scenario was produced to determine relative impacts to demand. *Table 11-1* below provides the AM peak westbound load and the daily ridership forecast between Arbutus and UBC. The lower enrollment assumption results in a 16% and 19% reduction in the peak directional load for the 2030 and 2045 horizons respectively. This reduction is lower than the 26% decrease in enrollment because the RRT ridership consists of students, who are directly affected by the enrollment assumption, and other users who are not directly affected (e.g. residents and employees).

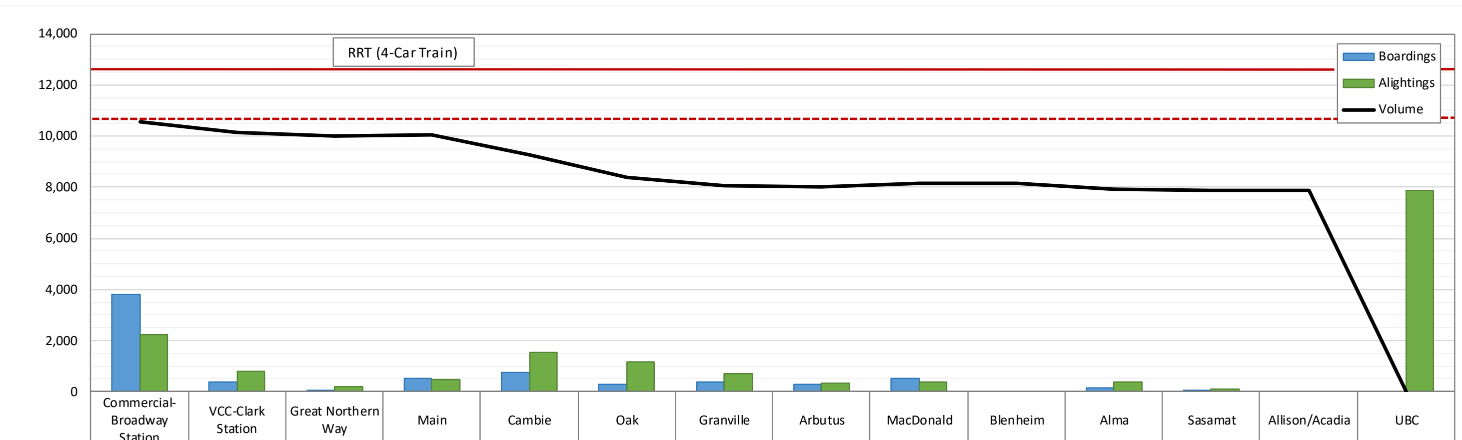
There is an approximate 14% reduction in total daily ridership between Arbutus and UBC which is less than the drop in peak directional load. The AM peak load occurs just east of UBC, where the proportion of students would be the highest on the corridor. Additionally, the AM peak period is dominated by commuter trips (including school trips), while in the other time periods, there are many other trip purposes. Therefore, it is expected that the enrollment assumption would have a lower impact on the daily ridership compared to the AM peak load.

Table 11-1: Low Enrollment Scenario Ridership Forecasts

	2030 RRT Scenario		2045 RRT Scenario	
	Peak Load	Ridership Forecast	Peak Load	Ridership Forecast
Base Land Use	8,100	96,500	10,000	118,800
Low Enrollment Land Use	6,800	83,100	8,100	101,800
Difference (%)	-16.0%	-13.9%	-19.0%	-14.3%

Figure 11-2 presents the boardings, alightings, and passenger volumes in the AM peak hour for the RRT option in 2045, assuming lower enrollment at UBC. Compared to the base land use scenario, applying a more conservative enrollment forecast results in a 19.7 percent reduction in the number of people commuting to UBC. Furthermore, the boarding and alighting activity with the low enrollment scenario is slightly higher between VCC-Clark station and Cambie station. This suggests that the RRT has become more attractive to those not commuting to UBC as it would appear less crowded with fewer students using the service.

Figure 11-2: WB AM Peak Demand Profile for RRT with Lower UBC Enrollment (2045)



	Commercial-Broadway Station	VCC-Clark Station	Great Northern Way	Main	Cambie	Oak	Granville	Arbutus	MacDonald	Blenheim	Alma	Sasamat	Allison/Acadia	UBC
Boardings	3,810	360	40	530	740	280	400	300	500	-	150	60	-	-
Alightings	2,210	810	180	470	1,540	1,150	710	340	380	-	370	90	-	7,890
Volume	10,580	10,130	9,990	10,040	9,240	8,370	8,050	8,010	8,140	8,140	7,920	7,890	7,890	-

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12. UBC STATION CAPACITY REVIEW

The UBC station is forecast to process over 9,800 passenger alightings in the 2045 AM peak hour. Considering that the busiest station today in terms of alightings is Burrard Station, which sees approximately 5,600 passenger alightings during the morning peak hour, there is concern that one station will not be able to handle this level of ridership in the future. This section provides a summary of comparable stations elsewhere that process similar levels of transit ridership. Further, the features of those stations were reviewed to determine requirements for the UBC station in 2045.

12.1 BENCHMARKING SIMILAR STATIONS ELSEWHERE

Two comparable stations were reviewed to determine whether 10,000 passengers per hour is feasible to process during a peak hour. There are examples of stations that handle much higher passenger flows but they tend to be on heavy commuter rail routes. The following sub sections describe these comparable rapid transit stations in the North American context.

12.1.1 Embarcadero Station – BART System

The Embarcadero Station is located in San Francisco's downtown financial district and is part of the Bay Area Rapid Transit (BART) system. This station currently handles approximately 10,000 passengers during the morning peak hour which is primarily made up of commuters going to work. This station is also connected to the Muni Metro (streetcar) and Muni bus lines. *Figure 12-1* shows the existing single platform on the BART line with potential future problems stemming from platform crowding, stair, escalator and faregate queuing and emergency exiting. This station is undergoing a modernization update to improve station functionality, safety, access, appearance and customer experience. This program aims to create more space on the existing platforms, improve vertical circulation capacity, provide real-time information and then implement long-term station capacity expansion such as new side platforms. These features including integration of the fare gate platform and the Muni Metro and BART lines are shown in *Figure 12-2*.

Figure 12-1: Existing Embarcadero Station Platform

Source:https://en.wikipedia.org/wiki/Embarcadero_station#/media/File:Southbound_BART_train_at_Embarcadero_station,_July_2018.jpg

Figure 12-2: Embarcadero Station Modernization and Redesign

Source: https://www.bart.gov/about/planning/embarcadero-montgomery_capacity_implementation_plan

12.1.2 St George Station – Toronto TTC System

The St George Station is part of the Yonge-University subway line which is a part of Toronto's TTC system. It provides a connection to the University of Toronto campus as well as the Annex neighbourhood and is also connected to the Bloor-Danforth Line and connecting bus services. This station sees approximately 12,500 passengers during the morning peak hour.

Figure 12-3 below displays the station entrance as well as the station platform. This station does have operational issues including crowding on the narrow platforms, crowding along the staircases as well as deficient capacity at the fare gates. To address these and other issues, the TTC is looking at future demand management strategies including the following:

- Fare restructuring to shift peak demands
- Improved pedestrian connections to GO trains
- Develop proposed "Relief Line" to relieve downtown transit capacity problems.

Figure 12-3: St George Station Entrance and Platform

12.2 UBC STATION REQUIREMENTS

This section reviews the key elements in designing a station at UBC that will be able to handle 10,000 passengers during the morning peak hour. The key components that will affect SkyTrain station capacity/limitations are illustrated in *Figure 12-4* and includes the following:

5. **Street / sidewalk:** No anticipated capacity issues at the UBC campus as students, faculty and staff will disperse to their lecture halls, research facilities and places of employment.
6. **Entrance:** No major capacity constraints with good design and urban integration.
7. **Fare Gates:** Can process up to 1,500 pphpd (up to 2,400 pphpd theoretical) based on observed volumes at other SkyTrain and Canada Line stations.
8. **Escalators:** Can process approximately 3,660-5,700 pphpd based on recent research[45].
9. **Stairs:** Typically used only if escalators are at capacity and provide additional passenger handling capacity if needed.
10. **Platform:** Need to provide adequate standing room and run-off areas to escalators and stairs so that crowding does not interfere with train operations.
11. **Trains:** Need to consider train configuration and number of doors as well as possible all-door boarding and alighting.

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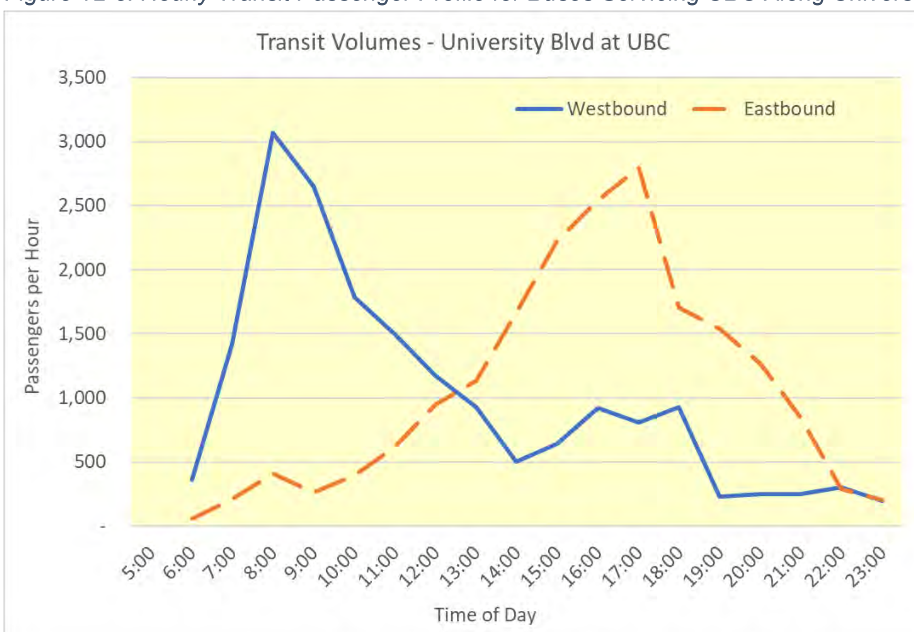
[45] *Al-Sharif, L., 1996, "Escalator Handling Capacity: Standards versus Practice", Elevator World.*

Figure 12-4: SkyTrain Station Key Components

Source: TransLink website. www.translink.ca

The key components that will likely require further consideration to ensure sufficient capacity are the fare gates, escalators, platform and trains. *Figure 12-5* below shows the hourly profile of transit passenger flows along University Blvd which illustrates a clearly defined morning peak which is mostly a function of class schedules. Note that off-peak flows in the morning are considerably lower than those in the peak direction. This hourly demand profile is assumed to remain relatively consistent for the future horizons unless travel demand management strategies such as time of day pricing are introduced to smooth out peak demands.

Figure 12-5: Hourly Transit Passenger Profile for Buses Servicing UBC Along University Blvd



A 2.5 minute assumed headway means that there will be 24 trains that arrive at the UBC station every hour. With ridership forecasts of 9,820 alightings in the 2045 AM peak hour, each arriving train will have on average about 410 passengers that will need to alight. In effect, transit users will have 150 seconds to disembark the train and clear the station platform before the next train arrives with another 410 passengers to process. Station design elements were considered in terms of processing this level of passenger activity and discussed in the following:

- **Fare Gates** – Will require at least seven gates to process forecast two-way passenger flows.
- **Escalators** – Will require at least four escalators to process the forecast two-way passenger flows. The peak flows could be further accommodated with the use of a reversible counter-flow escalator, similar to how Granville and Burrard stations operate today.
- **Platform** – May require all door boarding/alighting with two platforms depending on the future operating plan, transit consist and other station design features.

13. OPPORTUNITIES FOR BEST BUS SERVICE

The Broadway Subway Project will be built to Arbutus with the current plan to continue the 99 B-Line service to UBC. This section provides a review of opportunities for best bus service to maximize service levels along this segment considering features such as dedicated bus lanes, transit signal priority, bi-articulated buses, platooning buses and other operating efficiencies.

13.1 FEATURES OF CURRENT SERVICE

The existing 99 B-Line service runs with a peak headway of three minutes with articulated buses that have a seated capacity of 46 and total theoretical capacity of 120. *Figure 13-1* illustrates an articulated bus that is used on this route. TransLink's Transit Service Guidelines state that the peak capacity of an articulated bus is 75 passengers. There are currently over 2,000 passengers per hour[46] arriving at UBC in the morning peak hour with 20 buses per hour which results in approximately 100 passengers per bus; well above crowded capacity.

Figure 13-1: B-Line Articulated Buses

Source: TransLink website.

[46] *Based on observed Screenline data collected during fall 2017 at UBC.*

13.2 CONSIDERATION OF ENHANCED SERVICE

An enhanced service that is closer to bus rapid transit would replicate the existing service which provides six stops at Arbutus St, MacDonald St, Alma St, Sasamat St, Western Pkwy and the UBC bus exchange. This section looks at how much this service can be maximized in terms of frequency, vehicle type and operations based on best practices and available benchmarking information. The three primary metrics for this analysis include service headway, run time/operating speed and capacity. The following provides a description of each:

- **Service Headway** – The 99 B-Line currently operates with a three-minute peak service headway which is equivalent to 20 buses per hour. This is already a very high frequency and buses have operating issues such as bunching. Moving to a more frequent service at two minutes would perpetuate existing operating issues and would be difficult to achieve. There are however examples of other bus routes that operate at this frequency which is 30 buses per hour. At this high of a frequency, buses would catch up to each other and would not be able to maintain service run times. Based on the benchmark review of surface running LRT in *Section 5*, the shortest possible headway is two times the signal cycle for one-way operating, or four times the signal cycle for bi-directional service. With City of Vancouver signals running generally at 60 second cycle lengths, this results in a lowest possible headway of four minutes while being able to maintain optimal run times with TSP. Opportunities for meaningful gains through transit signal priority are therefore limited at two to three-minute headways.

- **Run Time / Operating Speed** – *Table 13-1* provides the range of operating speeds for different modes of travel. A best bus scenario with dedicated right-of-way and signal priority could operate from Arbutus to UBC in about 17 minutes which is approximately 25 km/h operating speed. This would be achievable with transit signal priority as well as bus queue jumpers at key intersections. The previous Phase 2 Evaluation developed a centre median running bus rapid transit system which would be able to run at similar operating speeds as LRT with signal priority.

Table 13-1: Travel Times and Operating Speeds between Arbutus and UBC

Mode	Peak Time	Off-Peak Time	Travel Speed
Auto	22 min	10 min	19-42 km/h
SkyTrain	10 min	10 min	42 km/h
LRT	17 min	14 min	25-29 km/h
Bus	21 min	15 min	20-28 km/h
Best Bus	17 min	15 min	25-28 km/h

- **Capacity** – Transit service capacity is determined by service headway and vehicle size. As mentioned, the current 99 B-Line operates with articulated buses that have a practical capacity of 75 passengers per vehicle with a theoretical capacity of up to 120 passengers resulting in a peak capacity of 2,400 pphpd. There are examples of bi-articulated buses that have higher capacities; in the order of 180 theoretical capacity per bus. These buses have an extra axle and second articulation joint which allows them to carry an additional passenger compartment. Bi-articulated buses do require more right-of-way, are not as maneuverable in an urban setting and require larger bus stop platforms to service passengers.

- Other Features – There are other features of transit service that can be optimized to provide the best possible service. This includes the following:
  - Stop procedure with all door boarding to allow passengers to alight and board transit vehicles as efficiently as possible.
  - Well-designed stops that are covered, well-lit for adverse weather and lighting conditions and a raised platform to allow for level boarding
  - Dedicated right-of-way to allow highest possible operating speeds with minimal interference from other roadway users.
  - Pre-boarding fare collection so that passengers can load buses without having to pay for their fare on the bus.
  - Real-time schedule information so that passengers are aware of arrival time for the next bus and they can be prepared to board as soon as the bus arrives at the stop.
  - Bus platooning to provide enhanced capacity, however this operating plan would require larger bus stops and a revised TSP strategy. Platooning of buses would only work effectively with lower service frequency and is not used widely in industry. This may change with adoption of automated vehicle technology that would allow buses to operate in a platooned configuration more effectively. Further an express bus that only stops at Arbutus and UBC could be considered to service passengers that are travelling from terminus to terminus, which represents the vast majority of riders on this segment of the corridor.

Features such as a dedicated bus-only lane, signal upgrades with transit priority and enhanced stops would require significant investment. Combining the information above, the theoretical maximum capacity along the Broadway/10th Ave corridor is 3,600 pph (30 buses per hour times 120 passengers per bus) with articulated buses that could provide 17-minute service from Arbutus to UBC. This is the highest theoretical capacity and it would be difficult to achieve a higher level of service with just bus-based technology (i.e. BRT).

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14. DEVELOPMENT OF PARTIALLY ELEVATED SKYTRAIN

For the purposes of developing the preliminary conceptual cost, this section considers the reduced construction costs of a partially elevated SkyTrain alignment. The segment west of Blanca was chosen for planning purposes only and does not preclude other scenarios from being considered. A tunnel portal west of Blanca was chosen for this analysis given it is a likely feasible location and minimizes impacts to properties and businesses along 10th Ave and Broadway. The "Millennium Line Broadway Extension (MLBE) Project – Strategic Options White Paper[47]" provides a thorough description of the feasibility and impacts of an elevated guideway through the denser and commercial areas of 10th Ave and Broadway. Further analysis of technical feasibility and trade-offs will be necessary in future work. A plan and profile of the guideway alignment was developed along with potential station locations in order to develop the cost estimates.

14.1 METHODOLOGY AND ASSUMPTIONS

There is a desire to look at a partially elevated SkyTrain alignment along the "Rail to UBC Rapid Transit Study" corridor from Blanca Street to UBC. This review takes into account grades and horizontal alignment options along University Boulevard from Blanca Street to a station at East Mall near the UBC Transit Exchange.

To develop a concept, the study team followed several design development stages assuming the future UBC SkyTrain corridor will follow W 10th Avenue. If the future tunnel alignment follows 8th Avenue to capture the Jericho Lands property, then an alternate route along 8th Avenue to University Blvd would be considered.

The design development stages followed to develop the conceptual guideway design and costing are:

1. Develop a plan / profile orthophoto from Blanca St to UBC showing building outline details, especially along East Mall, to assist in determining feasibility of an elevated system alignment along East Mall to serve a potential second UBC station (i.e. east or west side boulevard, sacrificing trees along the way).
2. Identify horizontal alignment route, minimizing traffic mobility impacts:
   - University Blvd – use centre median, diverting traffic as necessary to install pier foundations.
   - 80m radius at the intersection of University Blvd / East Mall while impacting the Wesbrook Building in the SE quadrant which is slated for redevelopment.
   - East Mall – along centre median, where possible, or along landscaped boulevard to the east or west depending on building locations. This corridor is constrained but with innovation, could be manageable to provide for a future potential second station.
3. Identify feasible locations for "UBC Station" near the UBC Transit Exchange. Other factors used to locate the stations were closeness to existing buildings, constructability, SkyTrain alignments, terminal tail track locations, and potential for SkyTrain extension southward.

[47] *Millennium Line Broadway Extension (MLBE) Project – Strategic Options Whitepaper, Ministry of Transportation and Infrastructure, Partnerships BC, March 2018 (https://engage.gov.bc.ca/app/uploads/sites/396/2018/09/StratOptions-Whitepaper.pdf) Section 7, Feasibility of Elevated SkyTrain Option, pages 26-30.*

4. Develop an existing ground profile along the route from Blanca St to “UBC Station” and along East Mall to a future potential station, identifying all street / access road crossing requiring preservation.
5. Develop a rough vertical top of rail profile assuming a 10m height above existing grade for maximum visibility under the guideway, determining connectivity between tunnel section east of Blanca St, transitioning to elevated.
6. Determine possible pier / locations at approximate 35m to 40m spacing, identifying clear-spanning road crossings.

14.2 GUIDEWAY PLAN AND PROFILE WITH STATIONS

The general approach for developing the SkyTrain guideway plan and profile with stations considered the following key principles:

- Following similar principles and considerations from previous alignments developed during the UBC and Vancouver alignment workshops;
- Determine alignment based on design criteria, feasibility and constructability;
- Minimize impacts (properties, trees, etc.);
- Minimize impacts to road network, property access and active modes;
- Respect minimum radius and maximum gradient requirements; and
- Location of transition from tunnel to elevated.

The SkyTrain alignment includes a tunnel portal just west of Blanca St. The guideway then runs at-grade along University Blvd following the existing ground profile and then becomes elevated just east of the golf course entrance. Generally, the guideway would run along the existing median along University Blvd. The rest of the guideway then runs elevated to its terminus location. The transition from University Blvd to East Mall would run through the existing Wesbrook Building which is slated for redevelopment. This would allow the trains to carry a higher speed through this segment and would also help to minimize noise and vibration effects. The guideway would then run on the east side of East Mall where it would transition to the median and then to the west side of East Mall near a future potential terminus station.

Considering the density of urban development and high property costs, having a tunnel portal east of Blanca St would be very difficult to achieve primarily because of the physical requirements for the tunnel portal. Further, the significant grade along 10th Ave between Alma St and Blanca St lends itself to a natural tunnel alignment with a portal just west of Blanca St which allows the alignment to travel at-grade through a portion of Pacific Spirit Regional Park, saving additional costs.

14.3 COST IMPLICATIONS

14.3.1 High Level Cost Estimates

Following completion of an approximate horizontal and vertical profile, the study team prepared a rough “high-level” cost estimate. Cost estimation is extremely volatile at this stage, considering the erratic nature of elevated, tunnel and at-grade transit construction costs from between 2016 and 2018, as editorialized in Metro Vancouver newspapers.

Using the May 12, 2018, “Rail to UBC Rapid Transit Study” estimate of $70M / km for LRT construction, the study team have assumed an at-grade guideway, with its power and LIM rail, is approximately 15% more than an at-grade LRT rail with power propulsion within trains and an elevated guideway to run approximately twice as expensive, as summarized in *Table 14-1* below.

Table 14-1: Unit Costs for Partially Elevated SkyTrain

SkyTrain Element	Calculation Methodology	Unit Cost
RRT (at-grade)	$70M / km x 1.15	$80M / km
RRT (elevated)	$70M / km x 2	$140M / km
Station (elevated)		$50M
RRT (tunnel)		$160M / km
Station (tunnel)		$100M

To compare SkyTrain elevated / at-grade to tunnel construction, the study team took RRT lengths from 180m west of Blanca St centre line where the SkyTrain tunnel would end and transition to elevated. Costs for the segment from Arbutus to Blanca are also included for reference.

Table 14-2: Guideway and Station Cost for Partially Elevated SkyTrain

	Guideway Type	Station	Length	Unit Cost	Ballpark Cost
Guideway	Tunnelled	-	4.5 km	$160M / km	$720M
	At-Grade	30+000 to 30+700	0.7 km	$80M / km	$55M
	Elevated	30+700 to 32+600	1.9 km	$140M / km	$265M
	Total Guideway		**7.1 km**		**$1,040M**
Stations	Tunnelled	3		$100M	$300M
	Elevated	1		$50M	$50M
	Total Stations	**4**			**$350M**
TOTAL					**$1,390M**

The following subsections provide a cost comparison of just the segment from Blanca to UBC.

14.3.2 RRT (Tunnel): 180m west of Blanca St to UBC

The cost estimate for RRT (tunnel) from Blanca to UBC is summarized in *Table 14-3.*

Table 14-3: RRT (Tunnel) 180m west of Blanca St to UBC

	Component	Length	Cost / km	Estimated Cost
RRT (Tunnel)	• Tunnel • Stations (1 x $100M)	2.6 km -	$160M -	$420M $100M
Total RRT (Tunnel) Blanca St to UBC				**$520M**

14.3.3 RRT (Elevated): 180m west of Blanca St to UBC

The cost estimate for RRT (elevated) from Blanca to UBC is summarized in *Table 14-4.*

Table 14-4: RRT (Elevated) 180m west of Blanca St to UBC

	Guideway Component	Length	Cost / km (as per above)	Estimated Cost
RRT (Elevated)	• At-Grade • Elevated • Stations (1 x $50M)	0.7 km 1.9 km -	$80M $140M -	$55M $265M $50M
Total RRT (Elevated) Blanca St to UBC				**$370M**

14.3.4 Total Cost Estimates

Assuming unforeseen contingencies (30-50%) are added to a four-year construction period with inflation (10%), the study team has applied a 40-60% total contingency to all cost estimates which allows for a range of construction cost estimates. The all-inclusive cost estimates for RRT (Tunnel) and RRT (Elevated) between Arbutus and UBC are detailed in *Table 14-5* using 2018 dollars.

Table 14-5: Comparison of RRT (Tunnel) and RRT (Elevated)

	RRT Tunnelled from Arbutus to UBC	RRT Tunnelled from Arbutus to Blanca + Elevated West of Blanca to UBC
Guideway & Stations	$1,540M	$1,390M
Maintenance Yard	$190M	$190M
Subtotal – Construction Cost	**$1,730M**	**$1,580M**
Project Management 12% x Subtotal	$210M	$190M
Vehicles	$200M	$200M
Property Acquisition	$220M	$220M
Subtotal – Soft Costs	**$630M**	**$610M**
Total Base Cost	**$2,360M**	**$2,190M**
Contingency / Inflation (40-60%)	$940-1,420M	$880M – 1,310M
Total (2018) Costs	**$3.3B to $3.8B**	**$3.1B to $3.5B**

14.3.5 Summary

The cost estimates developed above are summarized in *Table 14-6* below. These estimates should be considered indicative only based on the approach applied to determine them, substantially based on the May 1, 2018, Government of BC press release of the BSP and Surrey LRT cost estimates, as well as partially based on the breakdown of costs identified in the 2016 Evergreen Line PowerPoint presentation.

Only after a concept design has been developed can cost estimates be more reliably determined. Overall, however, an elevated SkyTrain alignment is approximately 30% cheaper to build versus a tunnelled alignment for the segment between Blanca and UBC. For the entire corridor, the partially elevated alignment is 7% cheaper to build the tunnelled from Arbutus to UBC.

Table 14-6: Comparing Two Options – RRT (Tunnel) vs. RRT (Elevated)

Option	Length	Preliminary Estimated Cost (2018 $)	Cost / km
RRT Tunnelled from Arbutus to UBC	7.1 km	$3.3B to $3.8B	$465 - 535M / km
RRT Tunnelled from Arbutus to Blanca + Elevated West of Blanca to UBC	7.1 km	$3.1B to $3.5B	$430 - 490M / km

PART 3: SUMMARY OF FINDINGS

15. SUMMARY OF FINDINGS

This section provides a summary of findings from Part 1 and Part 2 of this study and looks at the trade-offs for each of the technology and alignment alternatives. This is presented as information that could be used to support a commitment to a preferred technology and alignment alternative for further conceptual design and business casing purposes.

15.1 DISCUSSION OF PROJECT GOALS & OBJECTIVES

Based on the review of the 2012 Phase 2 Evaluation report, consideration of changes in the local context since that report was produced and taking into account best practice considerations as well as benchmarks from elsewhere, this section sets out a high-level summary for future planning and development of rapid transit alternatives between Arbutus and UBC. A review of the previous problem statement and project objectives provides a framework for conducting an assessment of rapid transit alternatives and trade-offs.

15.1.1 Validity of the Problem Statements

A review of the problem statement developed as part of the UBC Rapid Transit Line study, and in light of the current corridor context and recent trends, indicates that the considerations remain valid. The following provides an assessment of each of the key problem statements:

Problem Statement 1 – Existing transit services do not provide sufficient **capacity** or **reliable** enough service to the major regional destinations and economic hubs within the Broadway corridor

Assessment: Capacity and reliability issues continue to define the transit travel experience along the Broadway/10th Ave corridor

Problem Statement 2 – Transit trips and **mode share** need to increase to **reduce vehicle kilometres travelled** (VKT) and **GHG and CAC emissions**, both directly and by supporting the Regional Growth Strategy and other regional objectives

Assessment: The need to improve transit mode share and reduce VKT is all the more urgent based on the targets identified in TransLink's Regional Transportation Strategy (2013) and the City of Vancouver's Transportation 2040 Plan

Problem Statement 3 – Regional funding for transit is limited and needs **to balance a range of rapid transit investment priorities**.

Assessment: The need to make efficient and effective infrastructure decisions while balancing a range of regional transportation investment priorities remains.

15.1.2 Project Vision and Mission

It is considered that the Project Vision of a rapid transit line that services and shapes a region and communities and strengthens its livability by providing a viable alternative to the private car is all the more applicable in 2018 and into the future. This is especially true given housing affordability and transportation issues and the identified need for affordable multi-family housing that is well located relative to transit services which are essential to the region's economic sustainability and livability.

Similarly, the Project Mission of a rapid transit service that is accessible, convenient, safe, reliable, environmentally and financially sustainable and integrates with the regional transportation system remains valid (and is supported by best practice). Similarly, the achievement of transportation, environmental and land use objectives and targets which are clearly articulated in recent plans remains applicable.

15.1.3 Project Objectives

It is considered that the project objectives articulated in the 2012 Phase 2 Evaluation report also remain relevant, and are supported by considerations in recent TransLink, City of Vancouver and UBC Campus Plans, as well as the outcomes from recent studies (including the KPMG and ULI reports cited in *Section 3.1*). However, a closer and more explicit link between these objectives and a simplified evaluation framework can assist in refining the list of technology options and in identifying a preferred option.

15.2 CONSIDERATIONS FOR EXTENDING RAPID TRANSIT TO UBC

In addition to the mode share targets and capacity challenges identified in earlier parts of this report, various other considerations impact the evaluation of technology alternatives for extending rapid transit out to UBC. Key considerations that relate back to the overall project objectives are set out in the sub sections below.

15.2.1 Operating Speed & Line Time

Rapid transit line time is a function of operating speeds, vehicle performance (acceleration and deceleration), route distance, the number of stations as well as operating environment (e.g. grade separation, exclusivity of right of way, and the level of transit signal priority supported by an-at grade system).

The line time for LRT presented in the Phase 2 Report was based on an estimated operating speed of 29 km/h. However, the review of benchmark systems indicates that this is very optimistic for the Broadway/10th Ave corridor and that a more realistic average operating speed for LRT is around 20-25 km/h, closer to the average operating speed of the existing 99 B-Line service (18-20 km/h between Commercial-Broadway and UBC). Note that the 99 B-Line service operates faster and more reliably west of Arbutus. The average operating speed affects line time, the relative attractiveness of LRT and ultimately LRT ridership. Based on the benchmarking of other LRT systems and the operations model, an adjusted LRT operating speed of 25 km/h has thus been input to the updated ridership forecasts to provide a more realistic speed that still provides a significant advantage over the existing B-Line service. By contrast, the average operating speed of the existing Millennium Line RRT is 42 km/h, offering significant line time advantages.

The Phase 2 Report appears also to have over-estimated the potential time savings associated with transit signal priority (TSP), assuming 15-18 seconds of time savings per transit unit per intersection[48] for at grade systems. However, the report assumes that virtually all stopping time at minor intersections could be eliminated through the provision of TSP, which the review indicates is unlikely to be achievable given the ongoing need for pedestrian crossings. While time savings associated with TSP are dependent on the agency, the rules governing TSP operation, traffic conditions, etc., will affect the overall line time. The benchmarking review indicates that time savings of approximately 0.5 – 1 second per transit unit for each TSP-equipped intersection for vehicles operating in mixed traffic are more realistic, with somewhat higher savings achievable where LRT is operating in a designated lane, separated from other traffic.

To clearly understand the impact of operating speed, TSP and impacts to line times, an LRT operating model was developed to confirm these assumptions. This model showed that the average operating speed for the Modified LRT 1 scenario is 26 km/h and for the Combo 1 scenario is 25 km/h.

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[48] *Based on estimated time savings of 3-4 minutes per trip (compared to when operating at a 2-minute headway with reduced signal priority), indicating savings of 15-18 seconds for each of the 13 minor intersections described along the Broadway corridor (since no TSP would be provided at major intersections).*

15.2.2 Reliability

While reliability is an important factor impacting ridership, ridership forecasts assume steady-state conditions and do not typically account for variations in travel time. Reliability is thus considered separately here.

While all systems are subject to delays, for example as a result of unplanned breakdowns, grade separated systems avoid delays associated with traffic congestion, signalized intersections, and other traffic incidents and tend therefore to be more reliable. The numerous side streets which intersect with Broadway include signalized traffic and pedestrian intersections which slow the speed of at-grade transit along this corridor. Only the RRT alternative offers unimpeded right-of-way between stations, supporting speed and reliability of service.

Benchmarks from Skytrain and from other systems provide an indication of the relative reliability of different technologies. For example, Trimet's regularly published statistics[49] about on-time operations of the MAX LRT system indicate that between February 2017 and February 2018, the on-time reliability[50] of the MAX system varied between 83 and 89 percent. Each line of the MAX LRT system operates every 15 minutes with some combined segments operating approximately every 5 minutes. Expo and Millennium Line on-time performance[51] over the same period averaged at between 95 and 97 percent. Data specific to the 99-B line performance are available based on Coast Mountain Bus Company's Headway Performance Trend metric. 99 B-Line on-time performance ranges from 43-47% of scheduled trips arriving within 20% of the scheduled headway.

As is evident from these recent data, RRT technology offers considerably more reliable service than LRT and B-Line. Were the modelled ridership forecasts to include specific allowance for reliability, it is likely that they would show a higher differentiation between RRT and the other at-grade alternatives.

15.2.3 Impacts to Other Modes

One of the main differentiators between rapid transit alternatives is the right-of-way requirements for at-grade operations. The Broadway corridor has built up around and along the existing right-of-way and it would be challenging to fit a surface-running transit option (such as BRT or LRT) into the street without having impacts on other transportation modes and the public realm. Any street level alternative will require significant road right-of-way which will be challenging to fit in this physically constrained environment and will impact sidewalk widths, travel lane capacity, turning movements, parking, and nearby bike routes. All of the alternatives, with the exception of RRT, operate at street level and will interact with automobiles, trucks, pedestrians, cyclists, and others. These at-grade options can have a significant impact on the local community and urban streetscape in which they operate, affecting traffic speeds, connectivity for active modes, removal of street trees, the availability of parking, and especially safety. Further, an at-grade system would act as a barrier, perceived or otherwise, separating communities on either side. At-grade operations will also require turn movement bans at minor intersections due to sight distance and lack of space which will result in traffic using local streets to facilitate movements no longer possible due to turn bans.

At-grade alternatives will affect the capacity and reliability of not only east-west traffic, but north-south traffic for all modes having a negative impact on the traffic permeability and circulation. RTM3 was used to estimate impacts to automobiles along the Broadway corridor providing a travel time metric useful to differentiate the alternatives. *Table 15-1* provides a summary of westbound auto travel times from Commercial Dr to UBC along the Broadway corridor for the 2045 morning peak hour. As shown, RRT is the only alternative that provides benefits to other users, while all other alternatives negatively affect travel times.

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[49] See: http: / / trimet.org / about / dashboard / index.htm
[50] Where "on-time" is defined as departure (from a scheduled time point) not more than 1 minute early and no more than 5 minutes late relative to schedule.
[51] Defined as the percentage of trips delivered within three minutes of planned frequency.

Table 15-1: 2045 AM Peak Auto Travel Times from Commercial Dr to UBC Along Broadway Corridor

Rapid Transit Alternative	Travel Time	Difference
B-Line + BSP	36:30	-
Modified LRT 1	37:30	+3%
Combo 1	36:25	0%
RRT	35:10	- 4%

Many of the businesses along the Broadway corridor rely on street parking for access by customers and deliveries. Reductions in parking can impact customer access and local economic activity as would turn bans required at minor streets restricting access and requiring drivers to go longer distances to find parking. Businesses outside the downtown core are more reliant on street parking for customer access. Further, the Broadway corridor is characterized by a busy and active pedestrian realm with many people moving between stores and businesses on foot. Unless retained through general purpose lane reduction and property impacts, reductions to the width of sidewalks and pedestrian amenities, or loss of trees and landscaping, will impact Broadway's urban realm and the capacity and comfort of pedestrians.

15.3 RAPID TRANSIT ALTERNATIVE TRADE-OFFS ASSESSMENT

Summarizing information from the modelling, benchmarking and review of alternatives provides for a high-level evaluation of the rapid transit alternatives contemplated for the Broadway corridor. *Table 15-2* provides a summary of the key metrics to help differentiate the rapid transit technologies and alignments. This table provides information on what is being delivered for each alternative. In other words, each metric relates back to new infrastructure that is being considered. Each of the criteria in this table relates directly back to the principle objectives of providing a fast, reliable, cost-effective and safe service that attracts new riders, encourages economic development and is financially viable and constructible. Based on this review, each of the rapid transit alternatives meet some or all of the project objectives with varying degrees of compatibility. The information is presented here to support a preferred technology and alignment alternative that would be further developed through conceptual design, more detailed cost estimating, assessment of user benefits, all of which would be used to populate a project business case.

The following provides rationale for how each of the accounts were scored for each of the alternatives:

- **Transit Travel Time** – Both surface running LRT options improve line times over the B-Line alternative, however they both include a significant transfer penalty for passengers. RRT provides the fastest connection between Arbutus and UBC when measured with and without the transfer penalty. As shown in *Section 8.1.10*, the primary desire line is for passengers to travel through Arbutus to UBC. There is limited boarding and alighting activity at stations between Arbutus and UBC, including Arbutus.

- **Reliability** – Both of the surface running LRT options provide reliability improvement over the existing B-Line service. RRT, with grade separated operation, provides the highest levels of reliability with on time performance reaching up to 97% of scheduled trips.

- **Capacity** – The Modified LRT 1 and Combo 1 alternatives provide a significant increase in capacity over the B-Line service, however they are limited in terms of their future scalability. Only the RRT option has the scalable capacity to accommodate additional growth beyond 2045.

- **Peak Directional Load** – The Modified LRT 1 and Combo 1 alternatives attract more ridership than B-Line since they provide higher operating speeds and more capacity. RRT has the highest peak load since it attracts the highest levels of peak load for the segment between Arbutus and UBC. The Modified LRT 1 and Combo 1 alternatives are either nearing or over their maximum capacity in 2045. For RRT, the model shows that it is also nearing its practical capacity, however, RRT is expandable and could accommodate additional demand beyond 2045 by increasing frequency and train lengths.

- **New Daily Transit Ridership** – Both of the surface running LRT options provide a significant increase in daily transit ridership because of their improved operating speed and capacity over the B-Line alternative. RRT scores the highest as it attracts the highest levels of ridership to and from UBC due to its speed, reliability, capacity and transfer-free service.

- **Auto Travel Time** – All of the surface running alternatives have a negative impact to auto travel times. With RRT running with grade separation and the fact it attracts auto users to transit, it provides a travel time benefit to auto users measured from Commercial Drive to UBC.

- **Total Regional VKT** – Each of the alternatives has a minimal impact to regional vehicle kilometres travelled. The RRT alternative has the highest reduction in VKT as it attracts auto users to transit because of its faster, transfer free line time to UBC.

- **Preliminary Estimated Costs** – Each of the alternatives are significantly more expensive than continuing to operate with the existing B-Line service. The Modified LRT 1 alternative is the least expensive of the rapid transit alternatives given that it is surface running and has the shortest line length. The Combo 1 alternative is the next most expensive given that it has the highest line length but is still a surface running alternative. RRT is the most expensive alternative given that tunnelling was assumed along the entire corridor and that the vehicles and systems are the most expensive to implement. A review of a partially elevated SkyTrain guideway did show some cost saving potential.

- **Deliverability Challenges** – All rapid transit alternatives will face deliverability challenges; some more so than others. The key challenges for surface running LRT are developing the alignment in a dense, urbanized environment and the associated property and urban realm impacts. Also, the location of a standalone operations and maintenance centre will be challenging in the study area. For RRT, the key deliverability challenge will be developing the bored tunnel and where to locate the staging areas for the boring machine.

The findings and considerations set out above support investment in rapid transit from Arbutus to UBC. The technology, alignment and station location decision has not yet been reached for the section between Arbutus and UBC. Outcomes from the best practice review indicate that there are distinct advantages to eliminating less viable alternatives early on, while still supporting the flexibility to refine alignment and station locations during more detailed planning and design.

In considering this segment, most of the same conclusions and considerations from the previous Phase 2 Evaluation would apply. Most notably, the Phase 2 evaluation determined that RRT provides benefits over other options to transit and non-transit users; capacity and expandability; noise and vibration; safety and acceptability. Additionally, continuing SkyTrain for the segment beyond Arbutus would enable riders to avoid a transfer associated with a change in technology from SkyTrain to another alternative – this has ridership implications because of the associated travel time penalties and inconvenience of transferring between transit modes. At the same time, the built-up area of the corridor would be subject to right of way and urban realm impacts from an at-grade alternative, which could pose deliverability risks for Modified LRT 1 and Combo 1.

A long-term view is also recommended, given that development of rapid transit services is capital intensive and will be around beyond the land use forecasting horizon of 2045. Note that land use projections are based on existing zoning and does not reflect any land use reviews that could happen as part of rapid transit development. Rapid transit infrastructure will last 50 years or more, and it is important to ensure that infrastructure is not under built. A case in point is the Canada Line, where demand has outpaced expectations and is currently undergoing expansion to increase capacity through improved headways and longer trains. This is a case where future demand will likely exceed maximum capacity.

Grade separated RRT would provide distinct urban realm and reliability benefits over other alternatives. While vertical alignment has not yet been determined, it was assumed to be tunnelled for cost estimating purposes and a cost estimate was tested for an elevated alignment west of Blanca. For technical and functional reasons, elevated SkyTrain was not considered appropriate for the Broadway Subway Project (Millennium Line extension from VCC-Clark to Arbutus) except west of Blanca St. While the Broadway right-of-way is more constrained in the western part of the corridor than through Central Broadway, future analysis should assess the technical and functional feasibility of an elevated alignment west of Arbutus. In addition, a review of a potential second station at UBC is warranted given the scale of anticipated growth at the Point Grey campus.

Given that people travel to UBC from across the region and that the LRT options on Broadway would experience capacity issues in 2045, the network LRT scenarios considered whether the transit ridership could be captured by investing in an LRT network on two corridors, rather than just on the Broadway corridor. The analysis shows that if two LRT lines were constructed, there could be sufficient capacity to meet the forecasted transit ridership in 2045. However, in two of the scenarios, the Broadway corridor is overcapacity in the peak hour. Compared to the SkyTrain extension, the most extensive LRT network scenarios result in similar ridership to UBC but would likely generate higher ridership systemwide, roughly proportionate to the increase in capital cost. However, given that this would represent significantly more kilometers of rapid transit and given the need for a new operations and maintenance centre, two LRT lines would be considerably costlier than a single SkyTrain extension and require substantial supportive corridor and land use changes. Furthermore, the combined capacity could not be materially increased in the future if needed and the forecasts show that within 15 years of operation, demand is already approaching 80% of their practical capacity. In contrast, a SkyTrain's line opening day capacity could be roughly doubled over time if needed.

Table 15-2: Summary of Rapid Transit Technology Alternative Trade Offs

	B-LINE + BSP	MODIFIED LRT 1	COMBO 1	RRT
	B-Line from Arbutus to UBC	LRT from Arbutus to UBC	LRT from Main Street-Science World to UBC / LRT from Arbutus to UBC	RRT from Arbutus to UBC
TRACK LENGTH	–	7.1 km	12.0 km	7.1 km
NUMBER OF STOPS	–	5	10	4
TRANSFERS Expo Line to UBC Millennium Line to UBC	2 1	2 1	1 1	1 0
TRANSIT TRAVEL TIME In-Vehicle Time (mins) End-to-End Time Including Walk Access and Wait Times (mins)	20 22	17 19	28 / 17 30 / 19	10 11
RELIABILITY* On time performance (%)	55-67%	83-89%	83-89%	95-97%
CAPACITY Practical Capacity Theoretical Capacity Max Build-Out / Expansion Capacity	2,100 2,400 2,400	6,120 7,200 7,200	6,120 7,200 7,200	10,660 12,500 26,000
PEAK DIRECTIONAL LOAD (2045) Peak Load % of Practical Capacity	2,600 124%	5,900 96%	6,600 108%	10,000 94%
DAILY BOARDINGS (2045) On Arbutus-UBC Segment	28,800	66,100	135,300 / 100,500	118,800
NEW DAILY TRANSIT RIDERS/TRIPS (2045) Systemwide	–	4,000	16,000	13,600
AUTO TRAVEL TIME (2045) Time (mm:ss) from Commercial Dr–UBC (% difference relative to B-Line scenario)	36:30	37:30 (+3%)	36:25 (0%)	35:10 (-4%)
TOTAL REGIONAL VKT DURING AM AND PM PEAK PERIODS Total VKT (2045)	10.92 M km	10.93 M km	10.91 M km	10.89 M km
PRELIMINARY ESTIMATED COST (2018 $)*** Based on EGL and BSP unit costs Includes 40-60% contingency	–	$1.7B to $2.0B	$2.8B to $3.2B	$3.3B to $3.8B $3.1B to $3.5B**
DELIVERABILITY CHALLENGES	▪ Minimal	▪ At-Grade Alignment ▪ Business and property impacts ▪ OMC Requirements	▪ At-Grade Alignment ▪ Business and property impacts ▪ OMC Requirements	▪ Bored Tunnelling ▪ Business and property impacts at stations

** B-Line reliability is based on TSPR revenue hours not overcrowded.*
*** Cost for partially elevated SkyTrain west of Blanca*
**** Costs at the actual time of construction would be impacted by inflation between 2018 and construction period.*

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APPENDIX A: DEMOGRAPHIC PROJECTIONS

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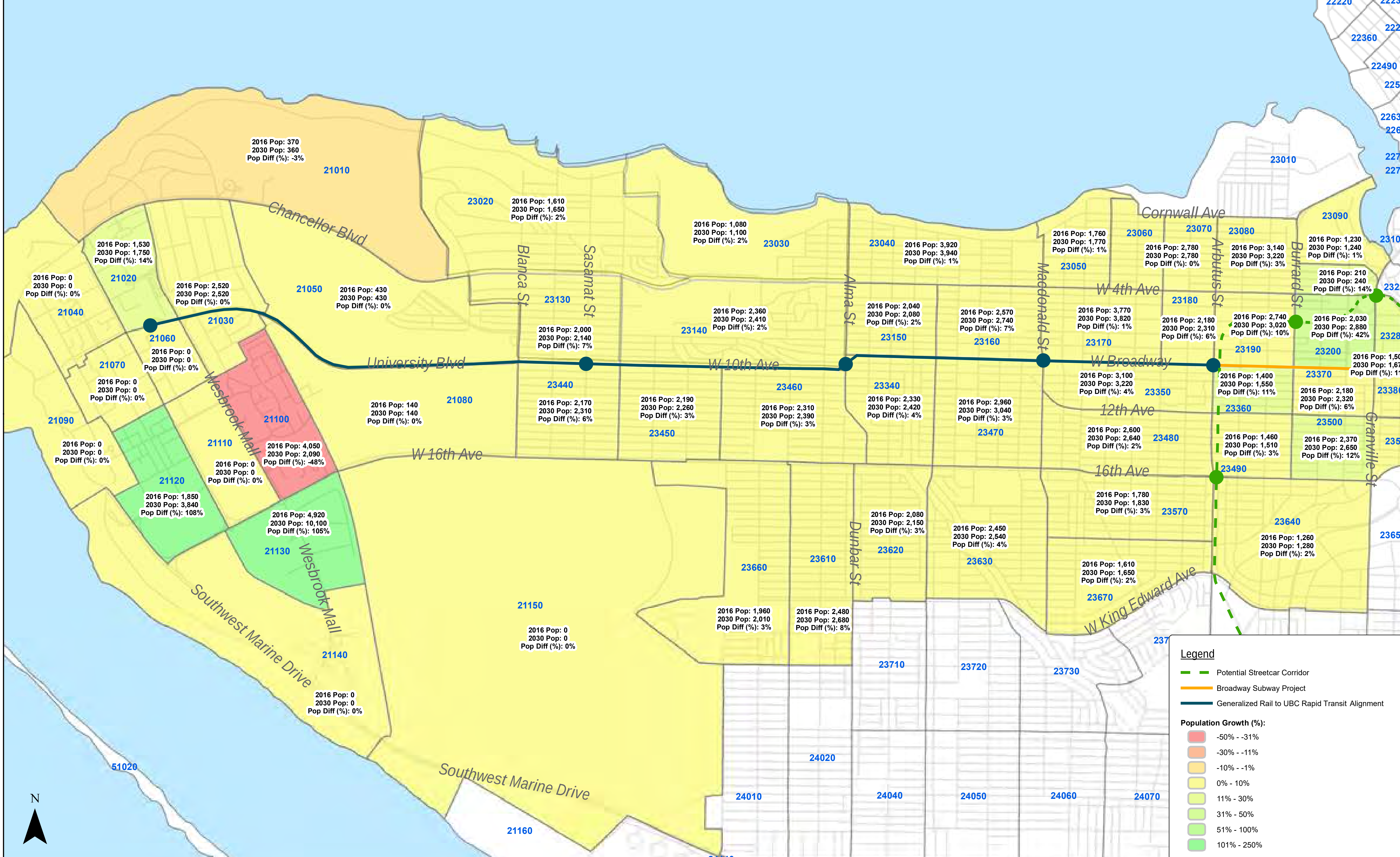
Rail to UBC Rapid Transit Study - Population Growth from 2016 to 2030



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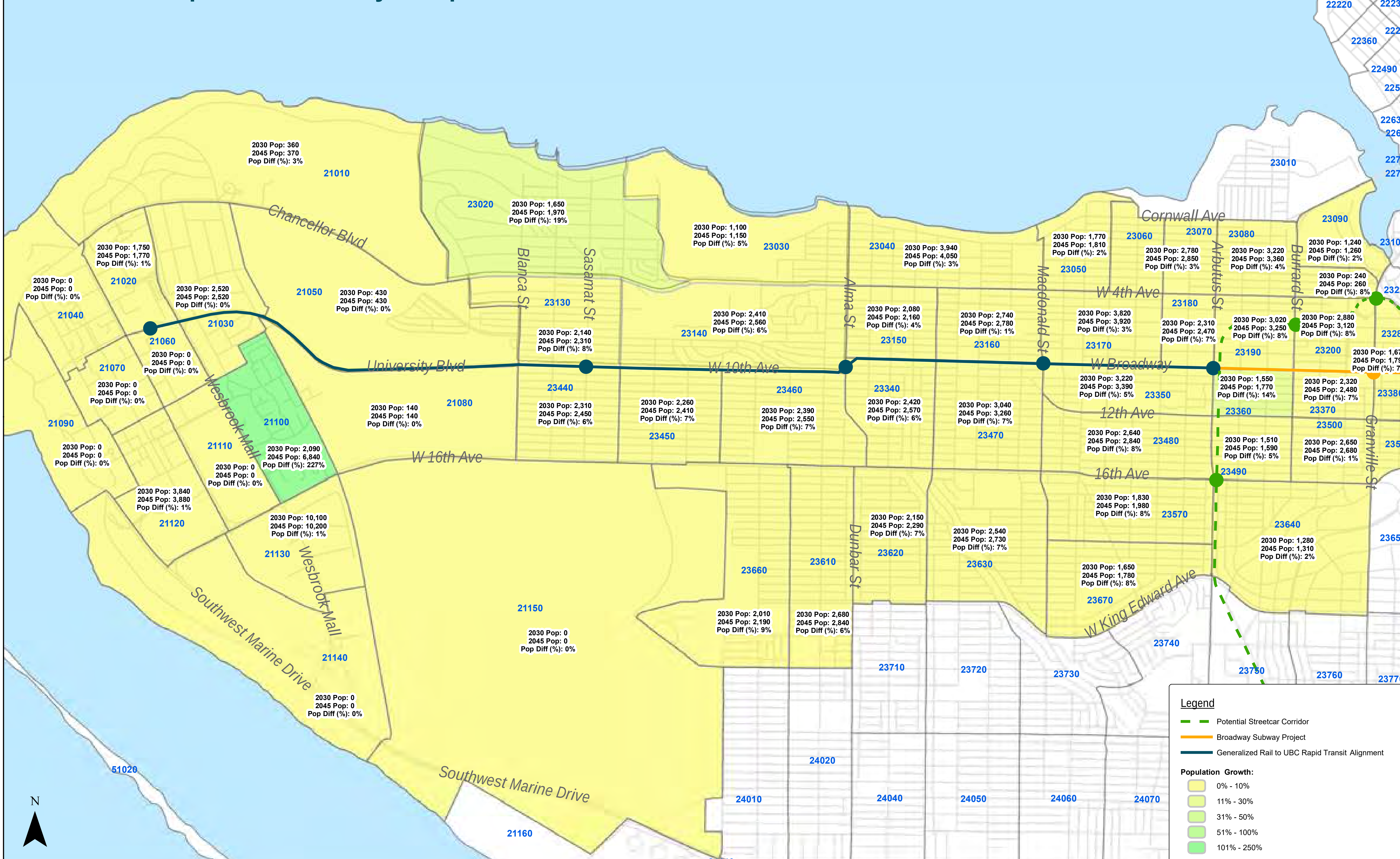
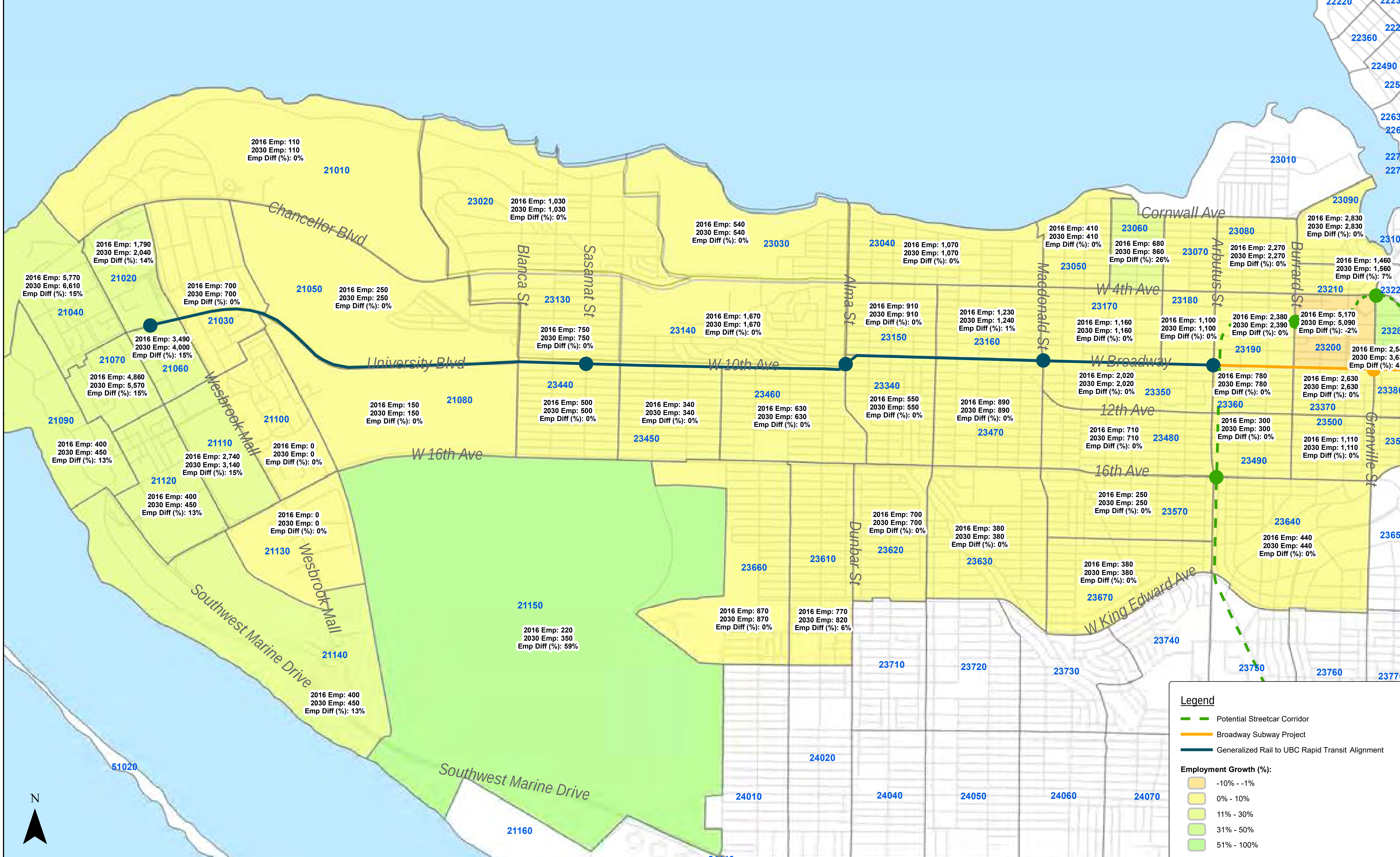
Rail to UBC Rapid Transit Study - Population Growth from 2030 to 2045



DRAFT

Rail to UBC Rapid Transit Study - Employment Growth from 2016 to 2030



Rail to UBC Rapid Transit Study - Employment Growth from 2030 to 2045

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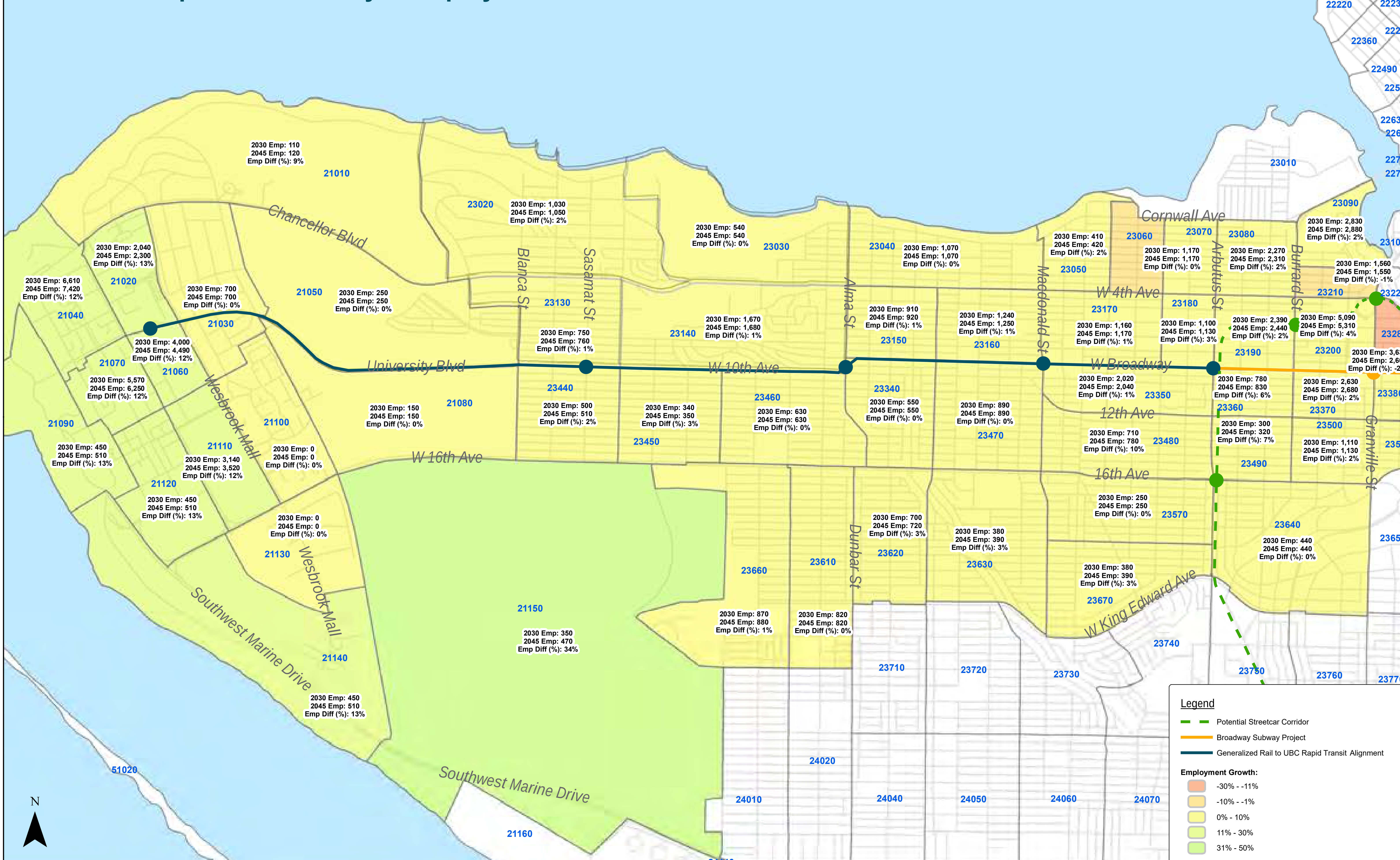
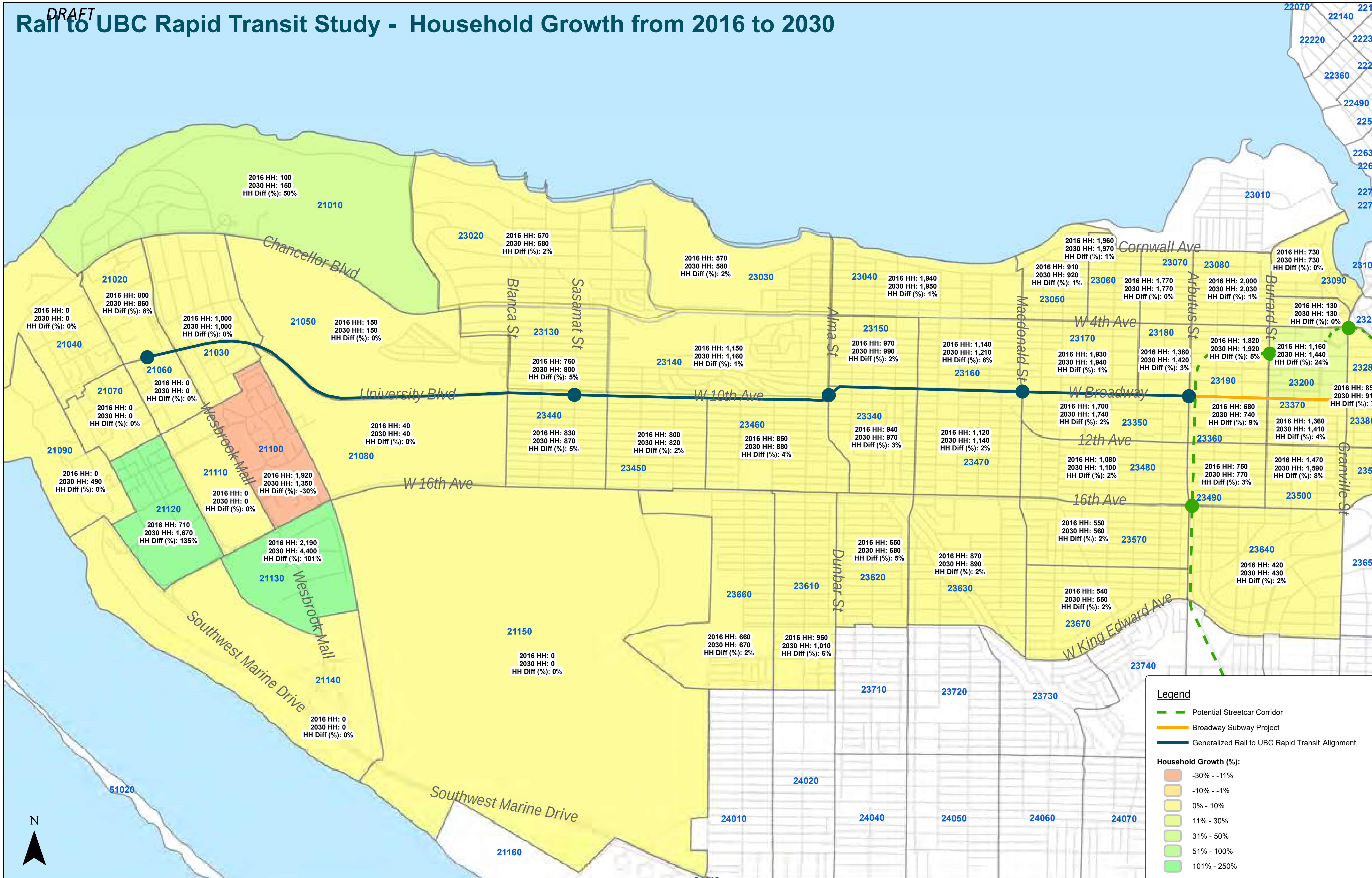


Rail to UBC Rapid Transit Study - Household Growth from 2016 to 2030



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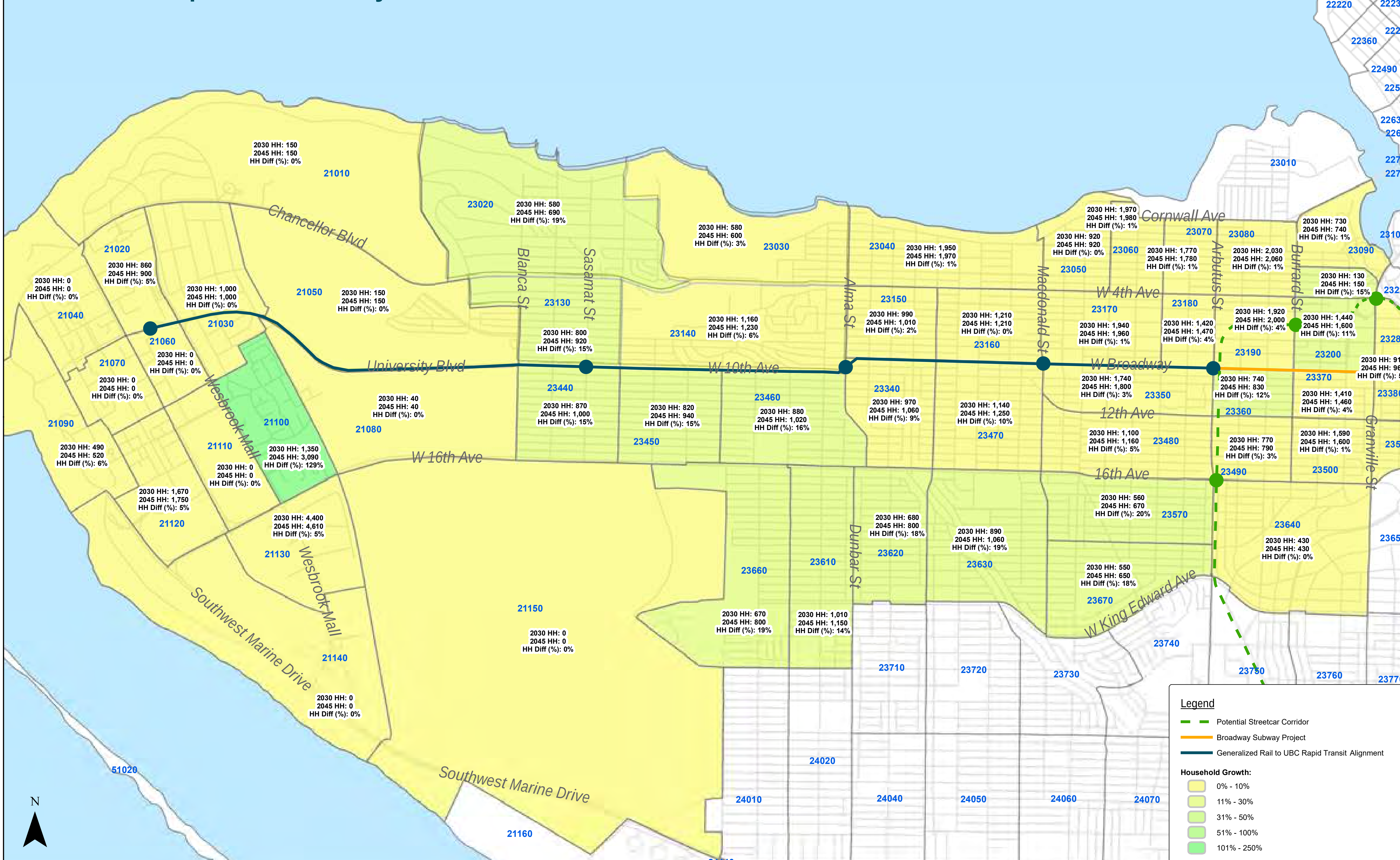
Rail to UBC Rapid Transit Study - Household Growth from 2030 to 2045



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APPENDIX B:
TRAVEL TIME VALIDATION

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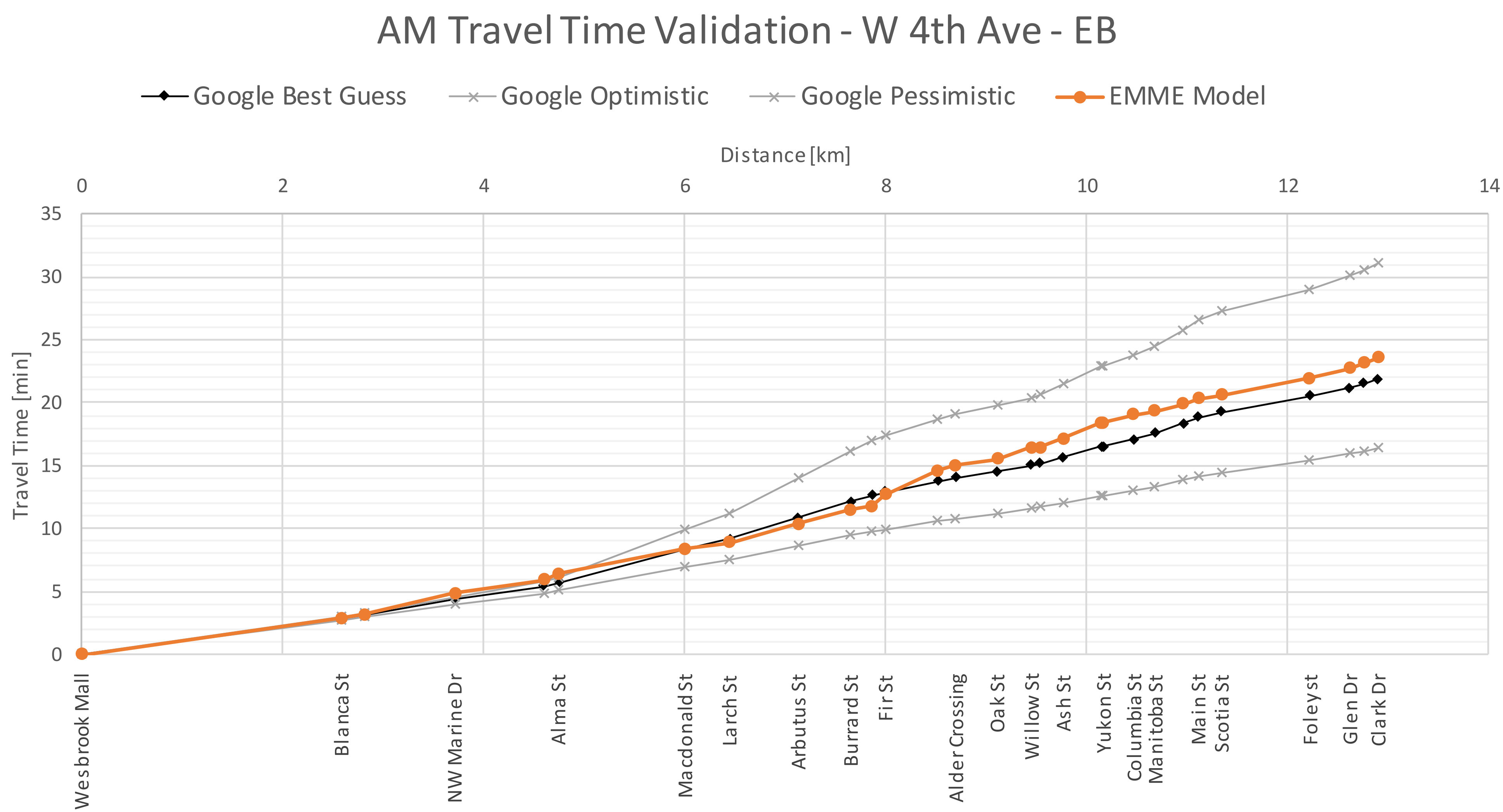
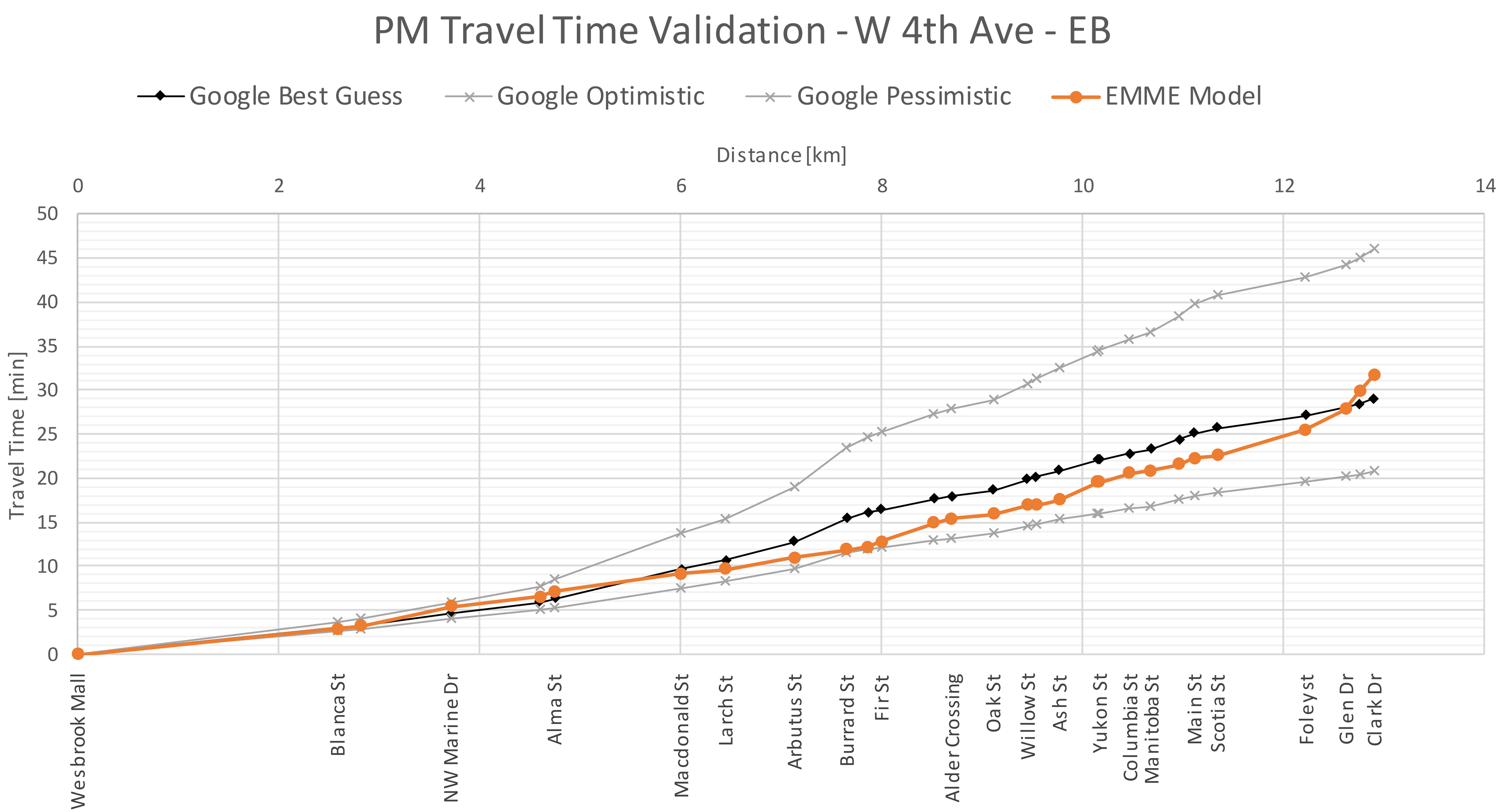

AM Travel Time Validation - W 4th Ave - EB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
14
Travel Time [min]
35
30
25
20
15
10
5
0
Wesbrook Mall
Blanca St
NW Marine Dr
Alma St
Macdonald St
Larch St
Arbutus St
Burrard St
Fir St
Alder Crossing
Oak St
Willow St
Ash St
Yukon St
Columbia St
Manitoba St
Main St
Scotia St
Foley st
Glen Dr
Clark Dr

DRAFT


PM Travel Time Validation - W 4th Ave - EB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
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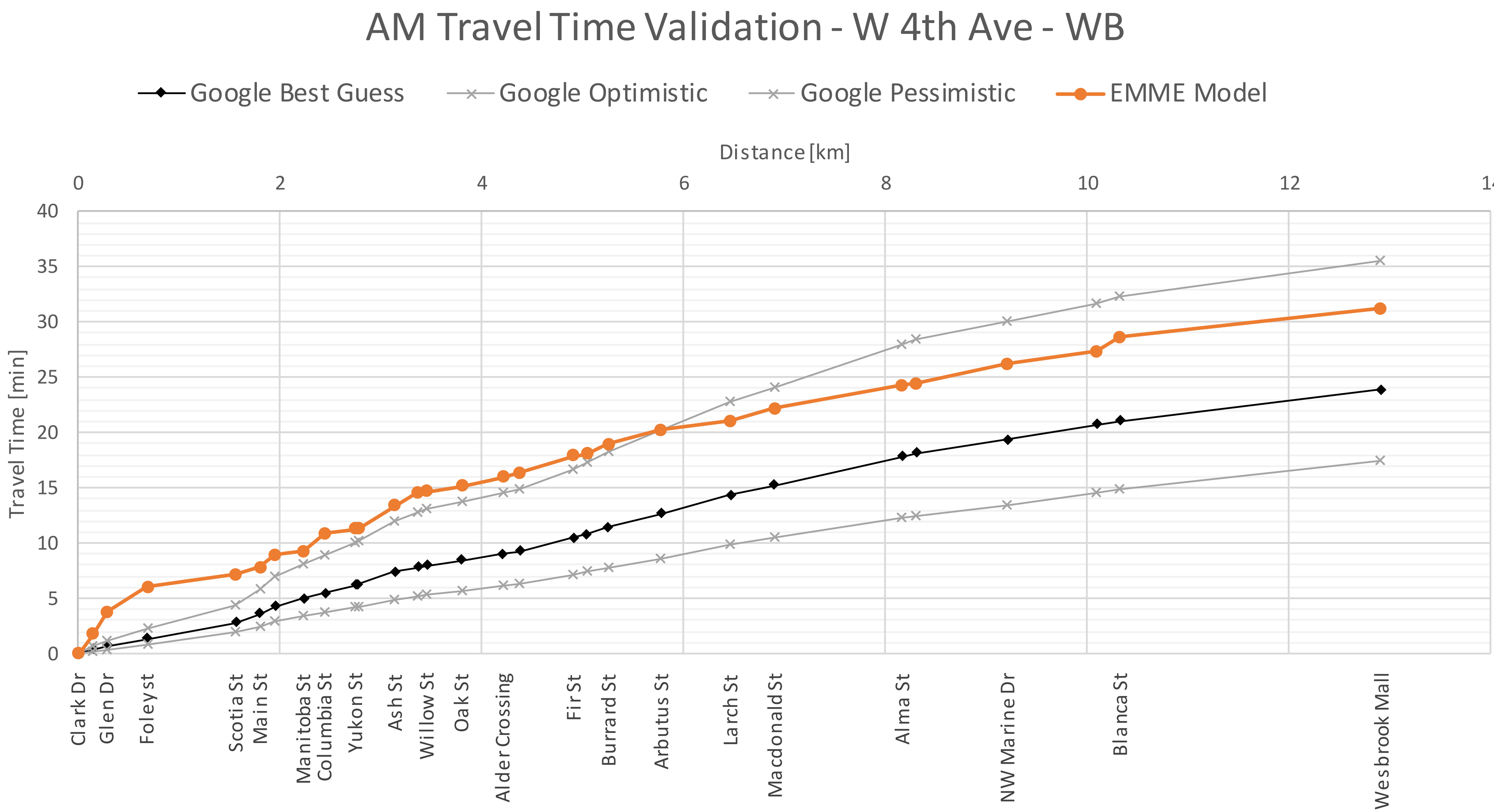
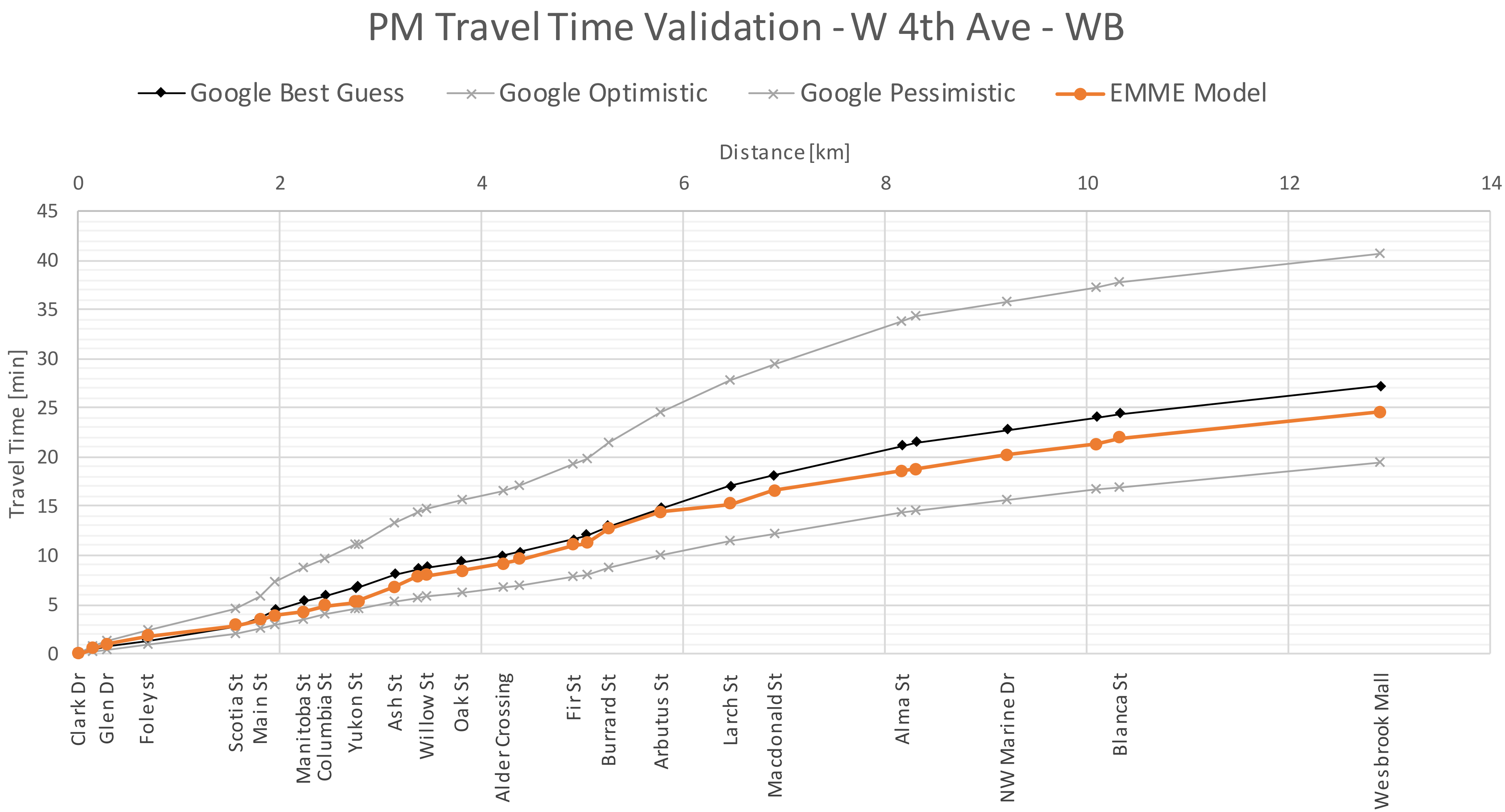
2
4
6
8
10
12
14
Travel Time [min]
0
5
10
15
20
25
30
35
40
45
50
Wesbrook Mall
Blanca St
NW Marine Dr
Alma St
Macdonald St
Larch St
Arbutus St
Burrard St
Fir St
Alder Crossing
Oak St
Willow St
Ash St
Yukon St
Columbia St
Manitoba St
Main St
Scotia St
Foley st
Glen Dr
Clark Dr

DRAFT



AM Travel Time Validation - W 4th Ave - WB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
14
Travel Time [min]
0
5
10
15
20
25
30
35
40
Clark Dr
Glen Dr
Foley st
Scotia St
Main St
Manitoba St
Columbia St
Yukon St
Ash St
Willow St
Oak St
Alder Crossing
Fir St
Burrard St
Arbutus St
Larch St
Macdonald St
Alma St
NW Marine Dr
Blanca St
Wesbrook Mall

DRAFT



PM Travel Time Validation - W 4th Ave - WB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
14
Travel Time [min]
45
40
35
30
25
20
15
10
5
0
Clark Dr
Glen Dr
Foleyst
Scotia St
Main St
Manitoba St
Columbia St
Yukon St
Ash St
Willow St
Oak St
Alder Crossing
Fir St
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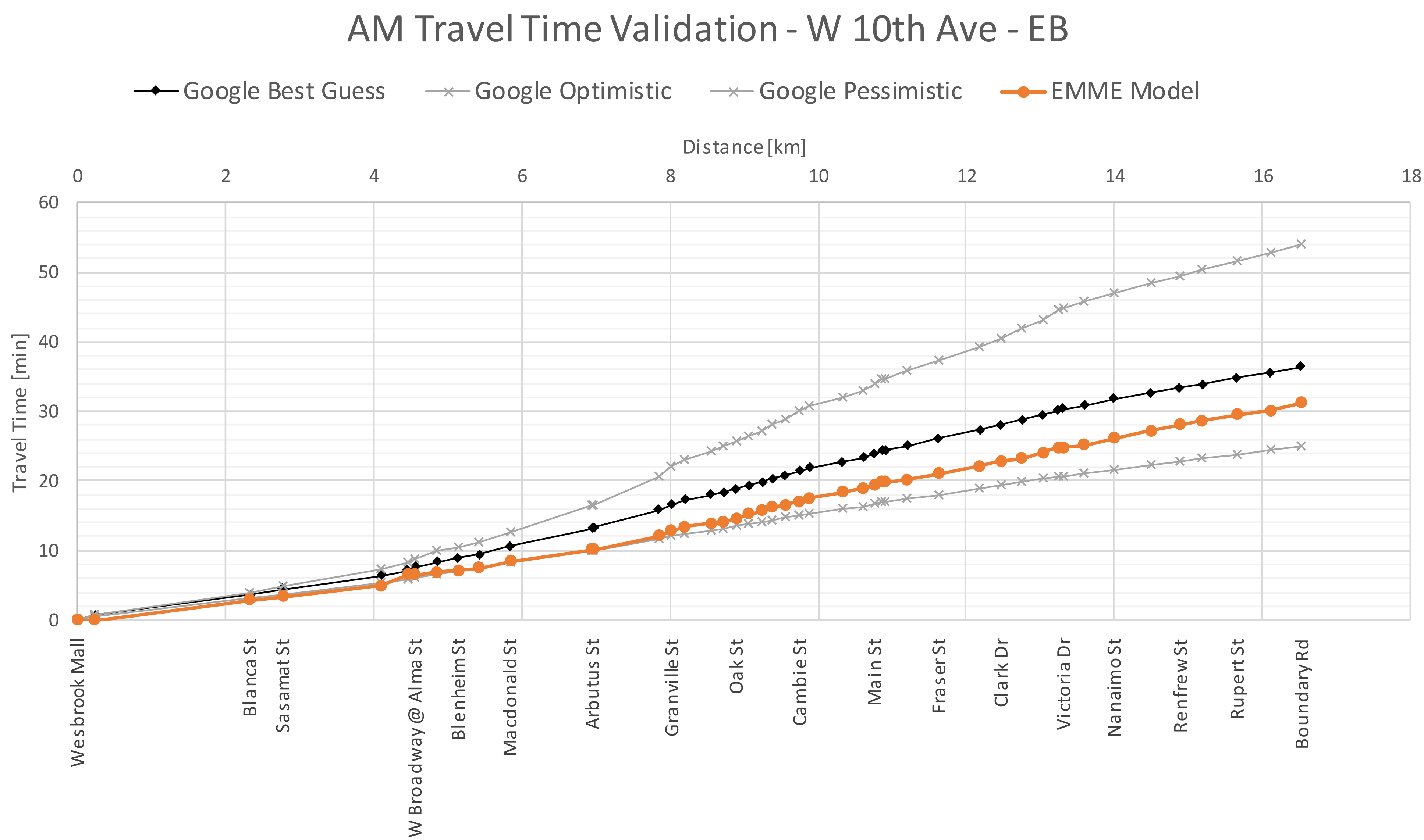
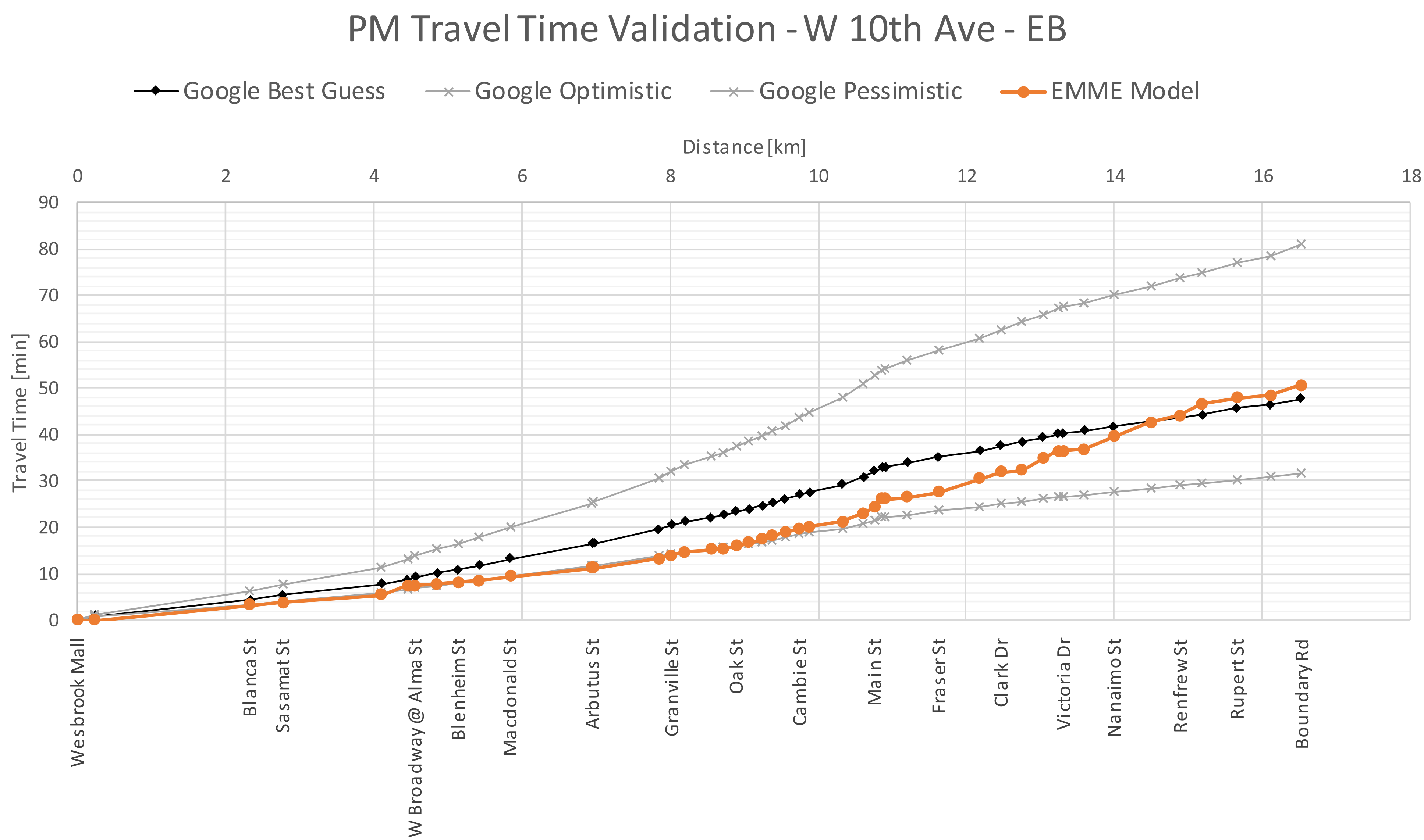
Arbutus St
Larch St
Macdonald St
Alma St
NW Marine Dr
Blanca St
Wesbrook Mall

DRAFT



AM Travel Time Validation - W 10th Ave - EB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
14
16
18
Travel Time [min]
60
50
40
30
20
10
0
Wesbrook Mall
Blanca St
Sasamat St
W Broadway @ Alma St
Blenheim St
Macdonald St
Arbutus St
Granville St
Oak St
Cambie St
Main St
Fraser St
Clark Dr
Victoria Dr
Nanaimo St
Renfrew St
Rupert St
Boundary Rd

DRAFT



PM Travel Time Validation - W 10th Ave - EB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
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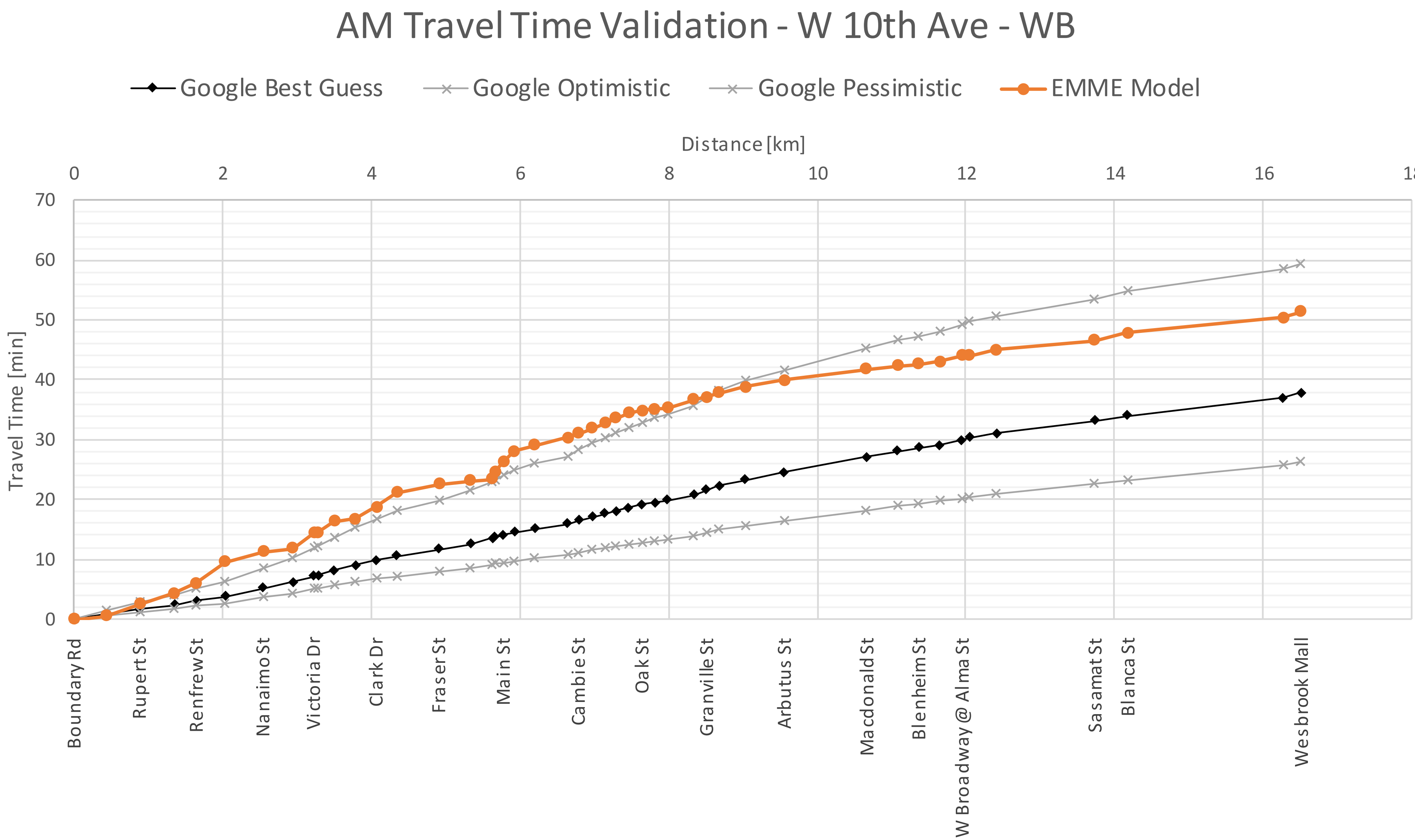
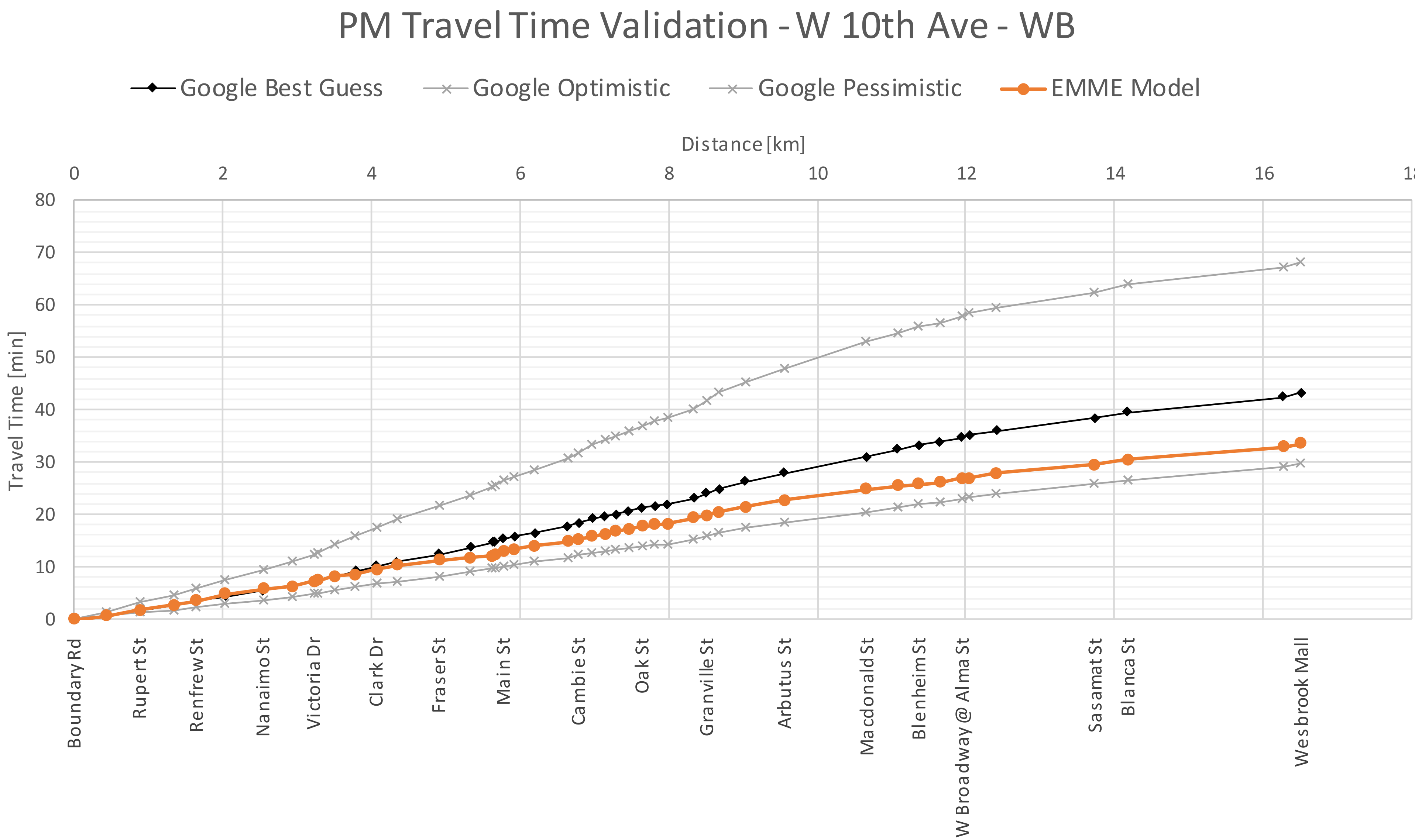
4
6
8
10
12
14
16
18
Travel Time [min]
90
80
70
60
50
40
30
20
10
0
Wesbrook Mall
Blanca St
Sasamat St
W Broadway @ Alma St
Blenheim St
Macdonald St
Arbutus St
Granville St
Oak St
Cambie St
Main St
Fraser St
Clark Dr
Victoria Dr
Nanaimo St
Renfrew St
Rupert St
Boundary Rd

DRAFT



AM Travel Time Validation - W 10th Ave - WB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
14
16
18
Travel Time [min]
70
60
50
40
30
20
10
0
Boundary Rd
Rupert St
Renfrew St
Nanaimo St
Victoria Dr
Clark Dr
Fraser St
Main St
Cambie St
Oak St
Granville St
Arbutus St
Macdonald St
Blenheim St
W Broadway @ Alma St
Sasamat St
Blanca St
Wesbrook Mall

DRAFT


PM Travel Time Validation - W 10th Ave - WB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
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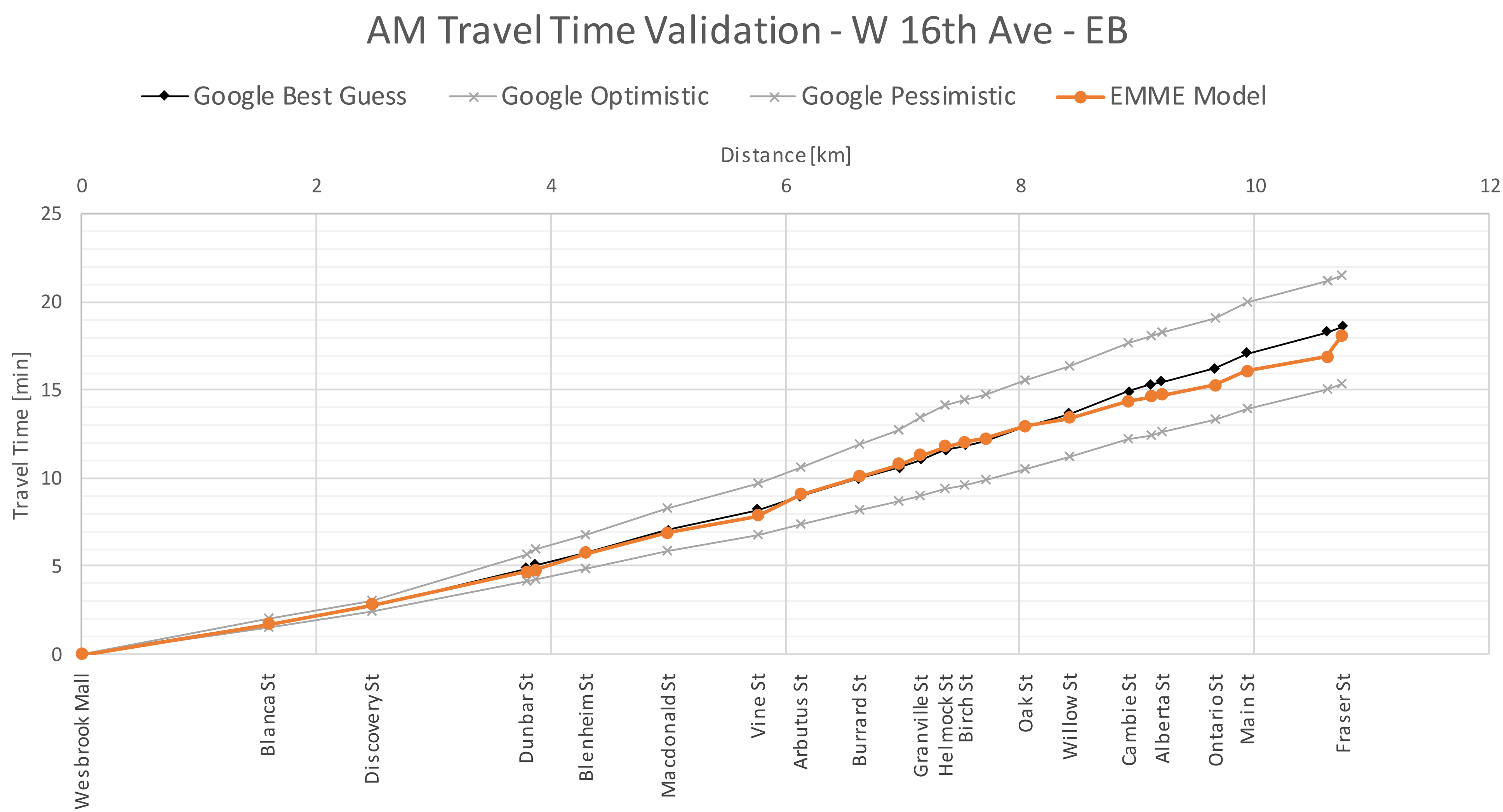
2
4
6
8
10
12
14
16
18
Travel Time [min]
80
70
60
50
40
30
20
10
0
Boundary Rd
Rupert St
Renfrew St
Nanaimo St
Victoria Dr
Clark Dr
Fraser St
Main St
Cambie St
Oak St
Granville St
Arbutus St
Macdonald St
Blenheim St
W Broadway @ Alma St
Sasamat St
Blanca St
Wesbrook Mall

DRAFT



AM Travel Time Validation - W 16th Ave - EB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
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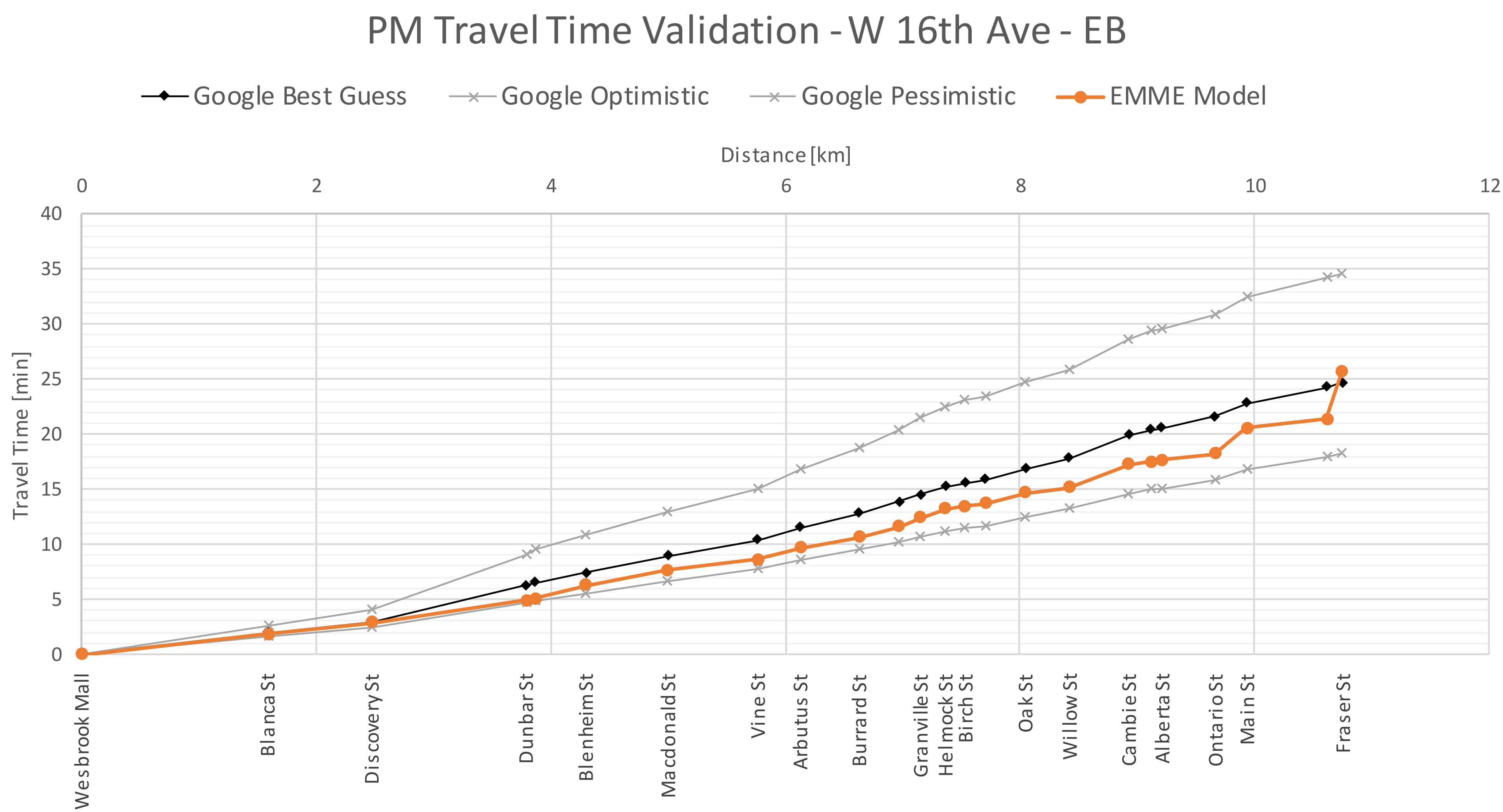
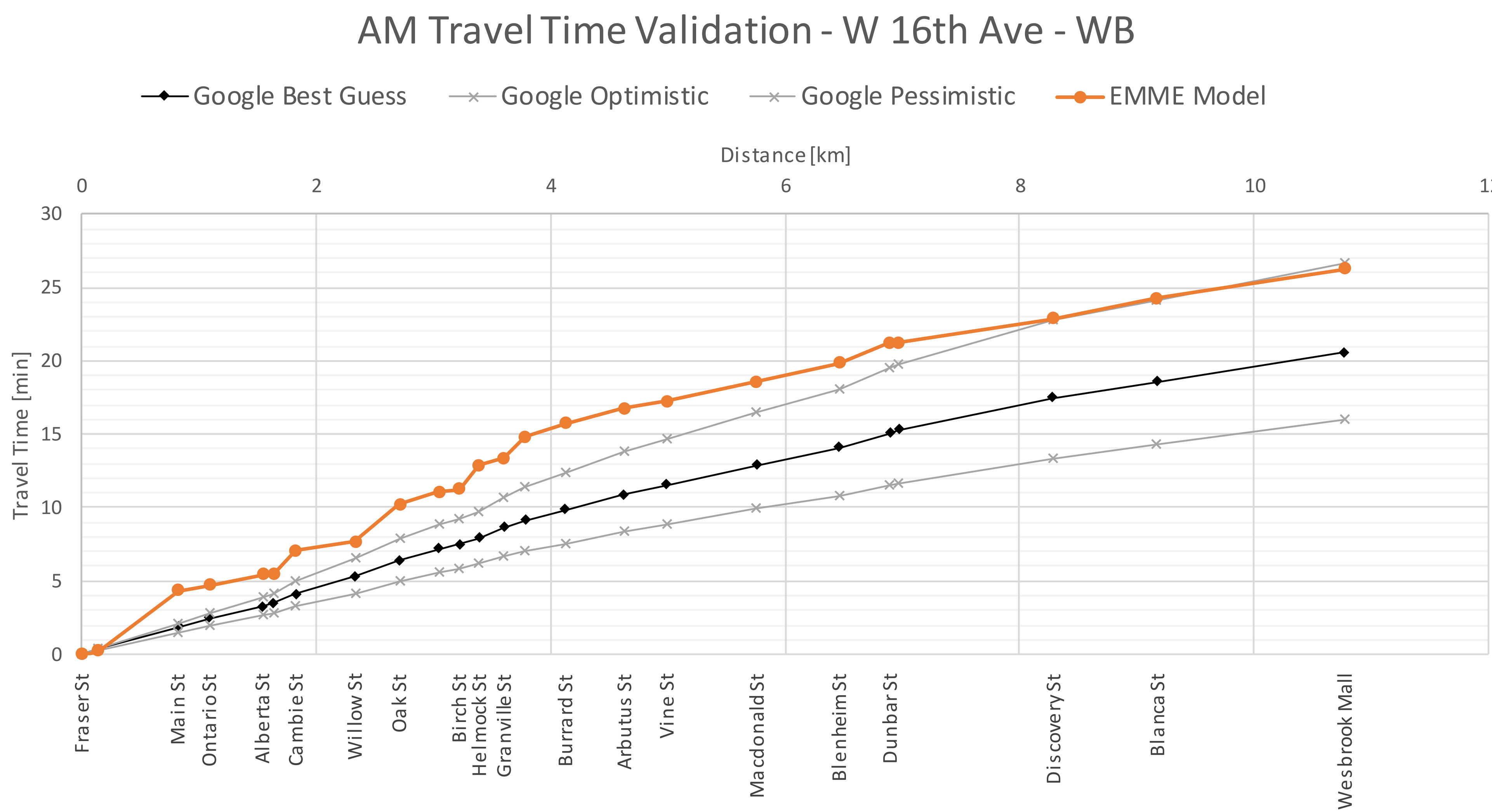
2
4
6
8
10
12
25
20
15
10
5
0
Travel Time [min]
Wesbrook Mall
Blanca St
Discovery St
Dunbar St
Blenheim St
Macdonald St
Vine St
Arbutus St
Burrard St
Granville St
Helmock St
Birch St
Oak St
Willow St
Cambie St
Alberta St
Ontario St
Main St
Fraser St

DRAFT



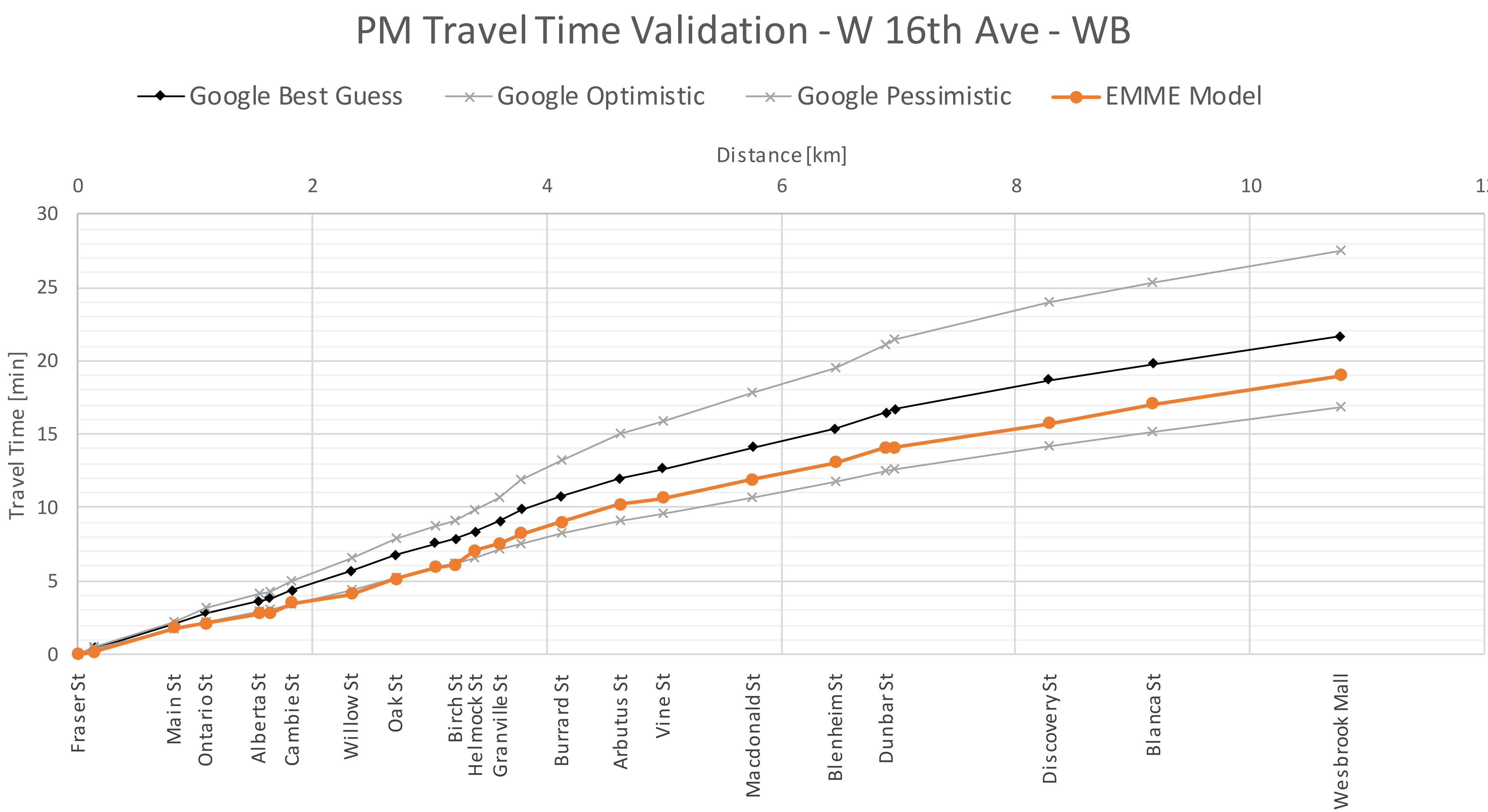
PM Travel Time Validation - W 16th Ave - EB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
Travel Time [min]
40
35
30
25
20
15
10
5
0
Wesbrook Mall
Blanca St
Discovery St
Dunbar St
Blenheim St
Macdonald St
Vine St
Arbutus St
Burrard St
Granville St
Helmock St
Birch St
Oak St
Willow St
Cambie St
Alberta St
Ontario St
Main St
Fraser St

DRAFT



AM Travel Time Validation - W 16th Ave - WB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
0
2
4
6
8
10
12
Travel Time [min]
0
5
10
15
20
25
30
Fraser St
Main St
Ontario St
Alberta St
Cambie St
Willow St
Oak St
Birch St
Helmock St
Granville St
Burrard St
Arbutus St
Vine St
Macdonald St
Blenheim St
Dunbar St
Discovery St
Blanca St
Wesbrook Mall

DRAFT



PM Travel Time Validation - W 16th Ave - WB
Google Best Guess
Google Optimistic
Google Pessimistic
EMME Model
Distance [km]
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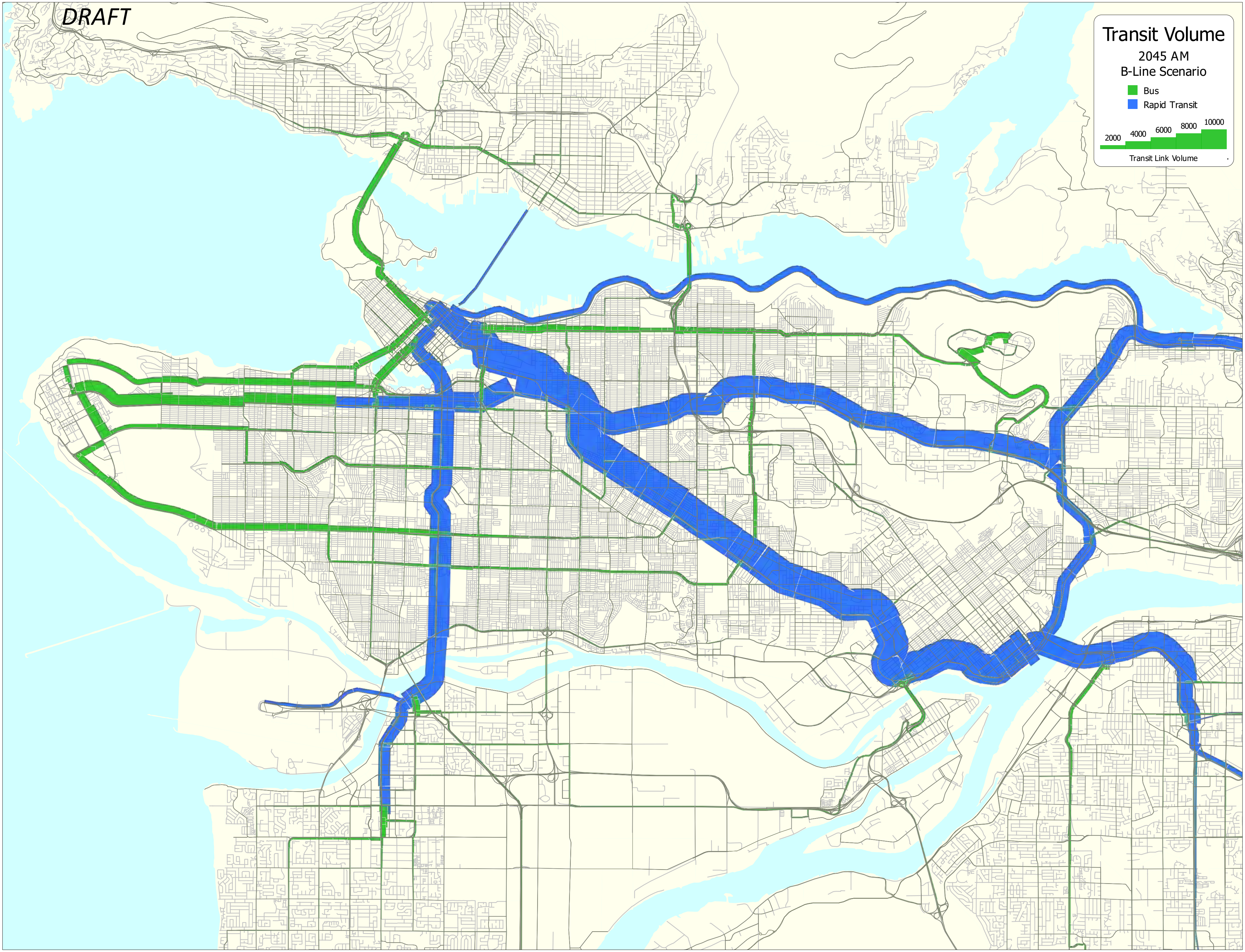
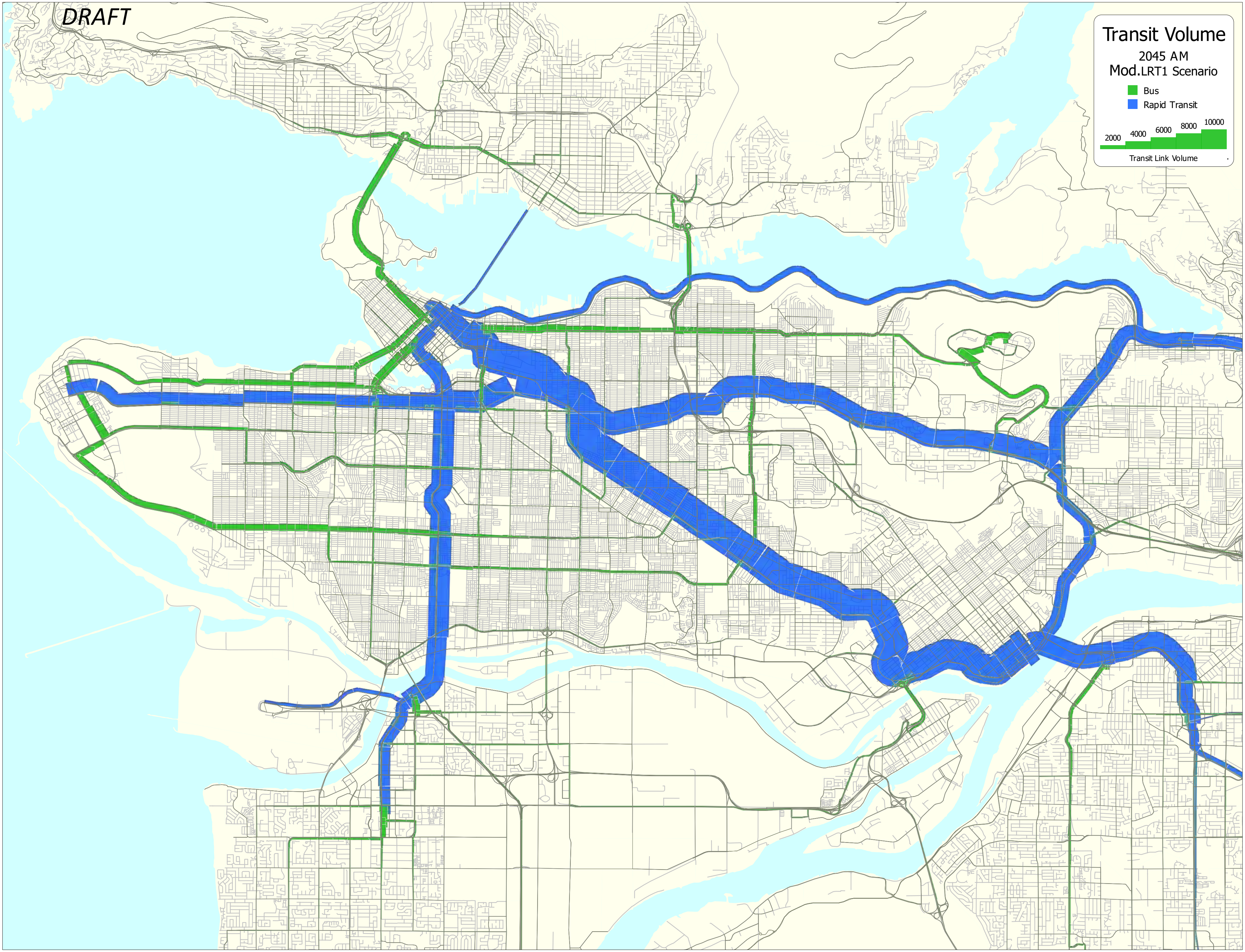
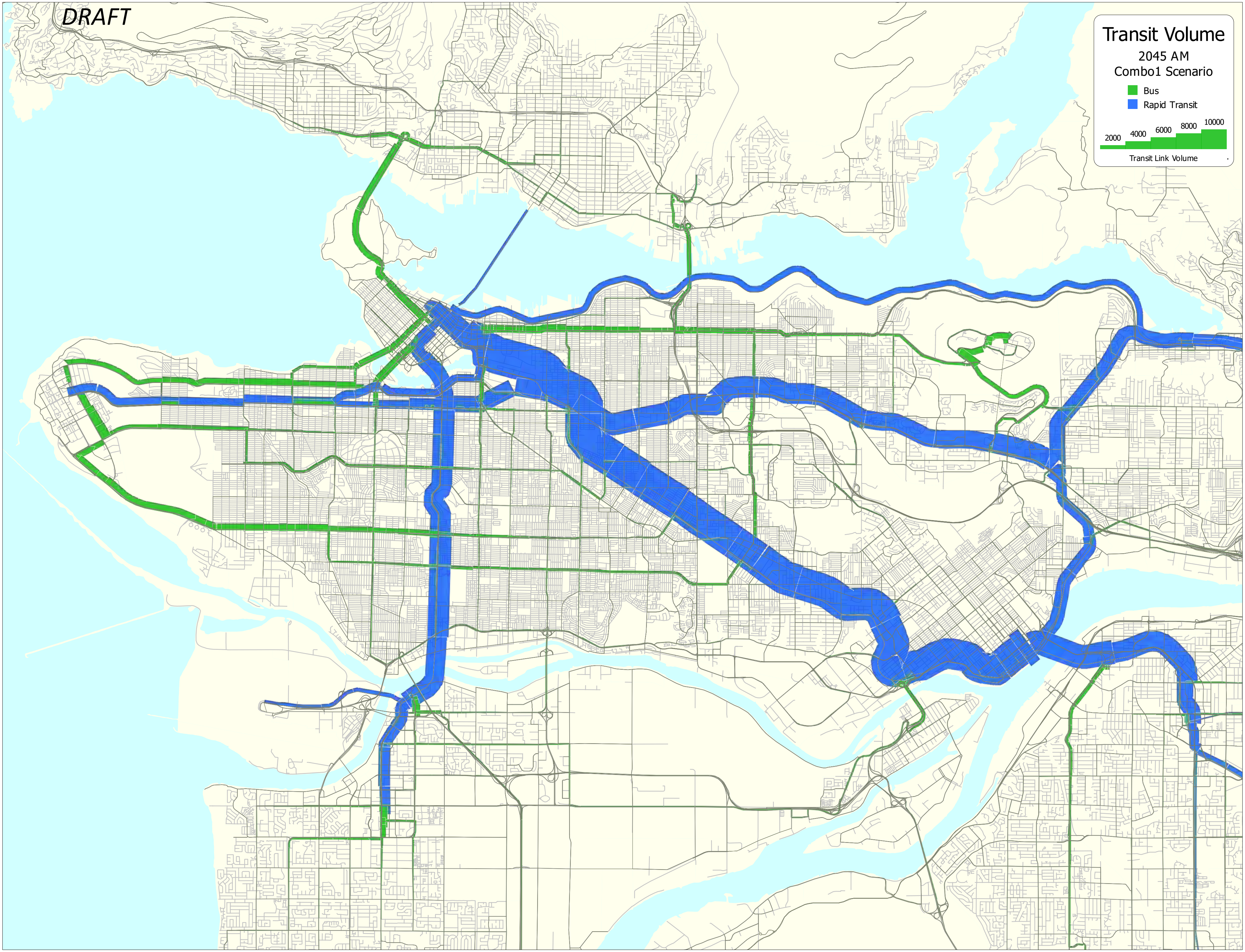
2
4
6
8
10
12
Travel Time [min]
30
25
20
15
10
5
0
Fraser St
Main St
Ontario St
Alberta St
Cambie St
Willow St
Oak St
Birch St
Helmock St
Granville St
Burrard St
Arbutus St
Vine St
Macdonald St
Blenheim St
Dunbar St
Discovery St
Blanca St
Wesbrook Mall

APPENDIX C: 2045 AM TRANSIT VOLUME PLOTS

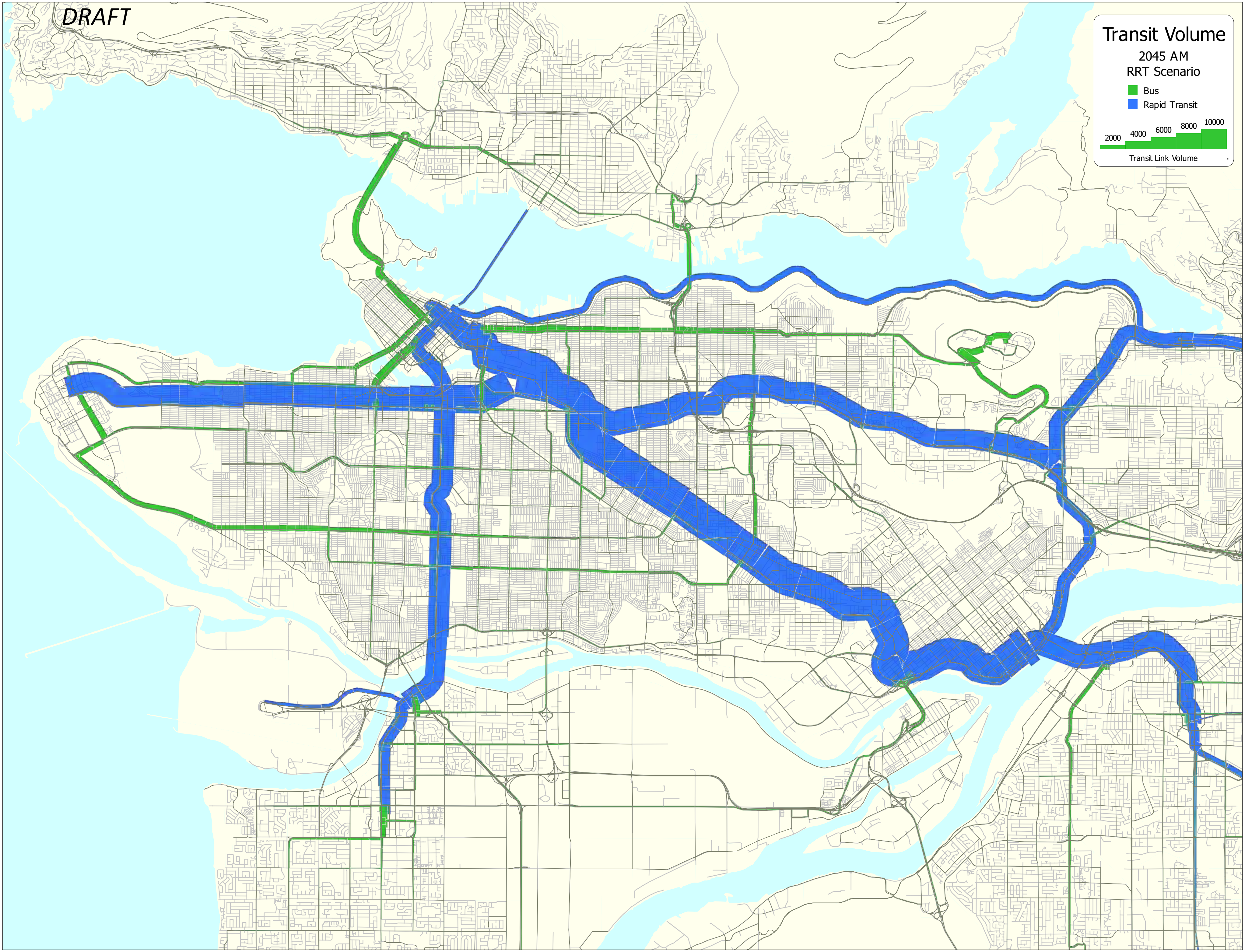

DRAFT
Transit Volume
2045 AM
B-Line Scenario
Bus
Rapid Transit
2000
4000
6000
8000
10000
Transit Link Volume



DRAFT
Transit Volume
2045 AM
Mod.LRT1 Scenario
Bus
Rapid Transit
2000
4000
6000
8000
10000
Transit Link Volume



DRAFT
Transit Volume
2045 AM
Combo1 Scenario
Bus
Rapid Transit
2000
4000
6000
8000
10000
Transit Link Volume



DRAFT
Transit Volume
2045 AM
RRT Scenario
Bus
Rapid Transit
2000
4000
6000
8000
10000
Transit Link Volume

APPENDIX D: LAND USE SENSITIVITY ASSUMPTIONS

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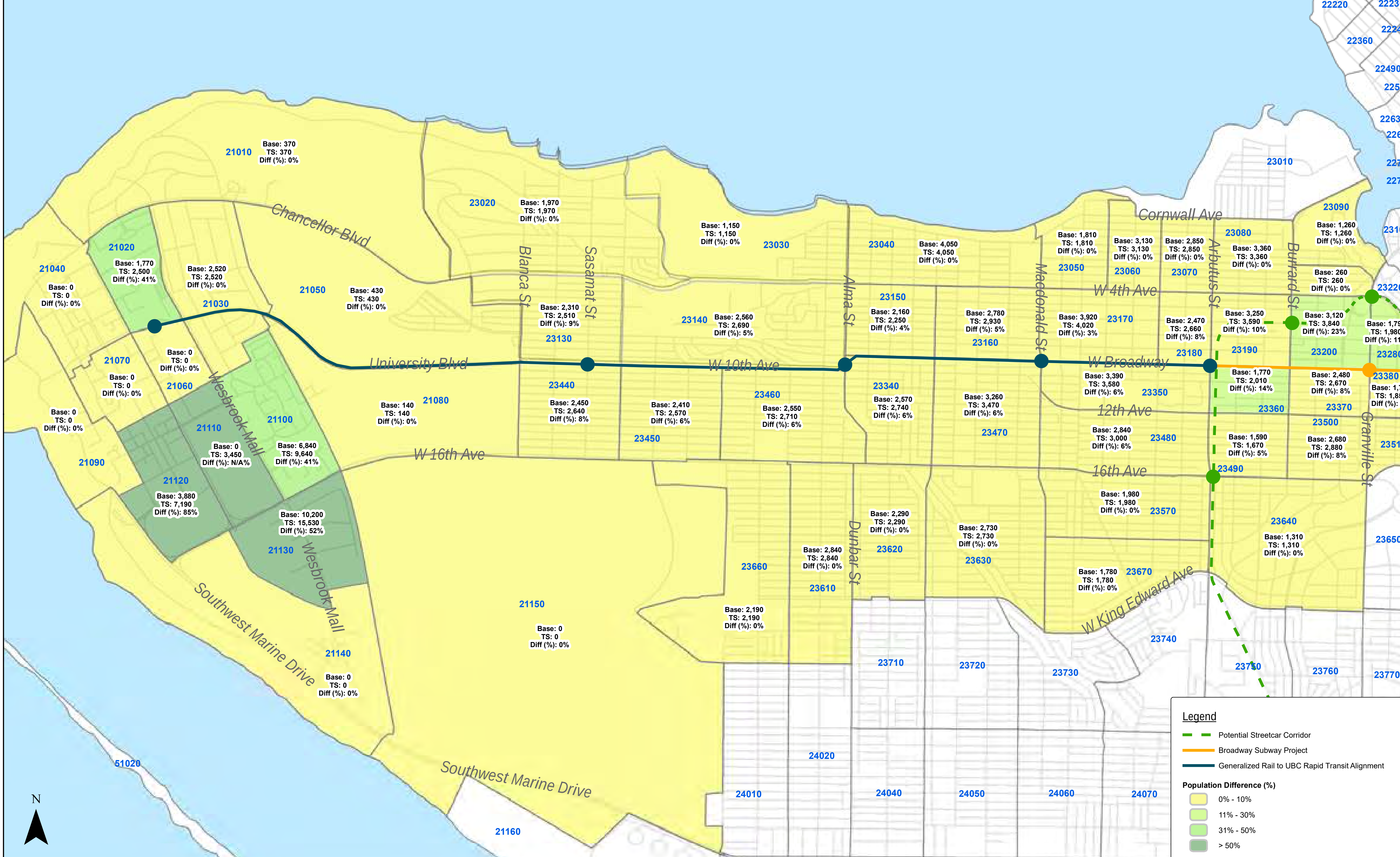
Population Differences Between 2045 Base and 2045 Transit-Supportive Land Use



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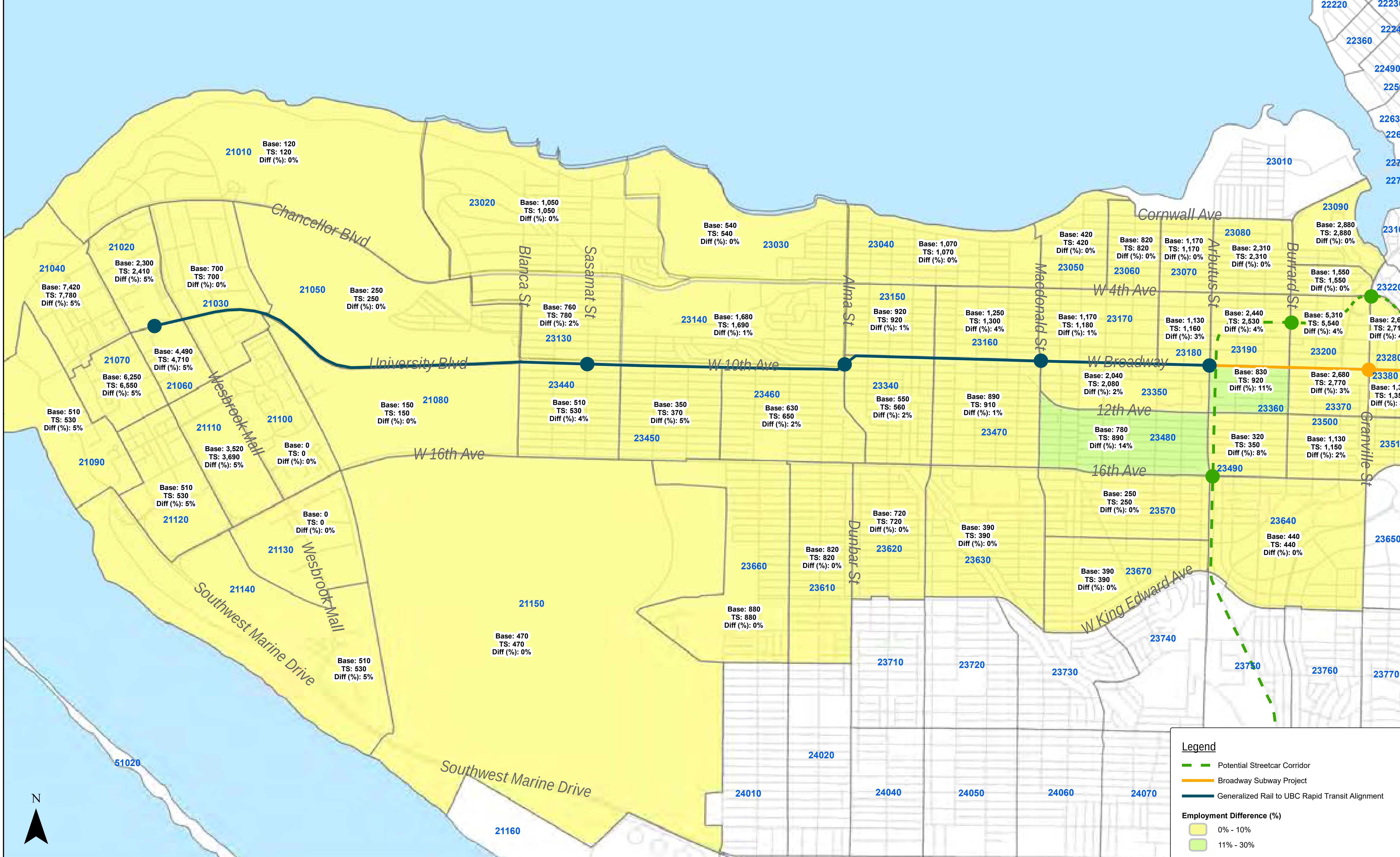
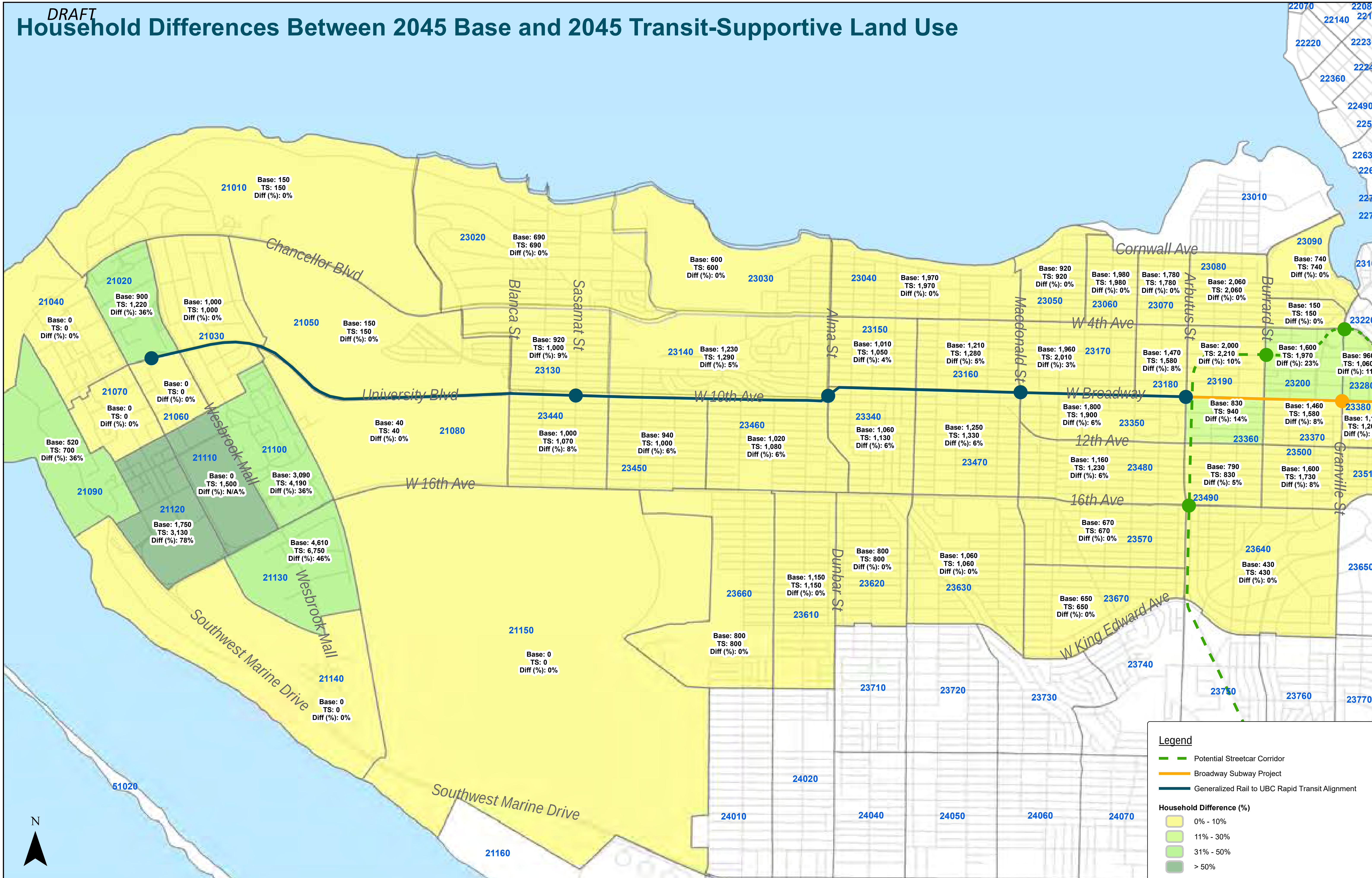
Employment Differences Between 2045 Base and 2045 Transit-Supportive Land Use



Household Differences Between 2045 Base and 2045 Transit-Supportive Land Use



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