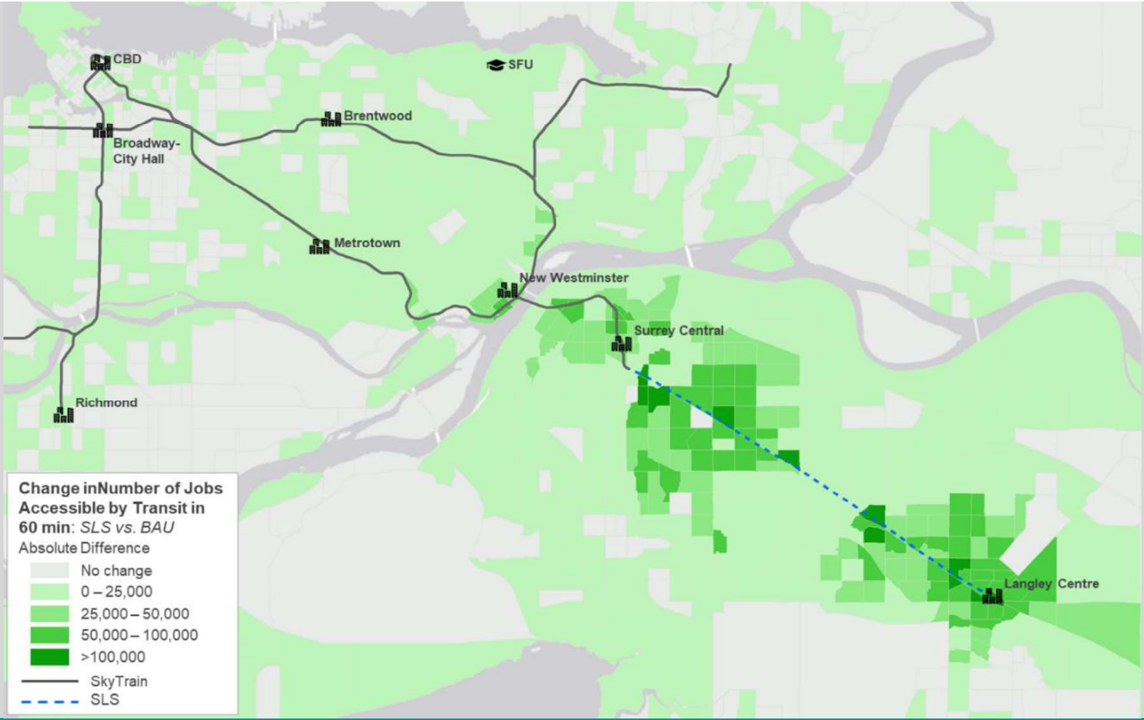

Surrey Langley SkyTrain Business Case Update – Economic Analysis – Revision #1

March 21, 2022

Submitted To Transportation Investment Corp.
Prepared by McElhanney

Prepared by
Ali Darwiche, PEng
adarwiche@mcelhanney.com

Reviewed by
Basse Clement, PEng
bclement@mcelhanney.com

Address
200 – 858 Beatty Street,
Vancouver BC Canada
V6B 1C1

Our file: 2121-00846-00

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Contents

1. Introduction 1

1.1. Background 2

2. The Regional Transportation Model (RTM) 2

2.1. Model Validation 3
2.2. Key Modelling Assumptions for Economic Analysis 3
2.3. Interpolation and Discounting 5

3. Methodology 6

3.1. ConventionalBenefits 7
3.2. Wider Benefits 9
3.3. Other Benefits 17
3.4. Qualitative Benefits 18

4. Project Benefits and Life Cycle Economic Outcomes 20

4.1. Benefits and Costs Summary 20
4.1. Economic Outcomes 20

5. Economic Analysis Sensitivity Outputs 24

Tables

Table 2-1: Economic Analysis Key Assumptions 3
Table 3-1: User Benefit Streams 6
Table 3-2: Auto and Transit Annual Travel Savings (Minutes) 8
Table 3-3: Annual Incremental Fare Revenue in 2016 Dollars 8
Table 3-4: Annual Truck Travel Savings 9
Table 3-5: Annual Auto & Truck Travel Time Reliability Savings (Minutes) 11
Table 3-6: Annual Transit Travel Time Reliability Savings (Minutes) 11
Table 3-7: Cost of Collision by Type 12
Table 3-8: Annual Reduction in Number of Collisions 12
Table 3-9: Metro Vancouver $CO2_e$ Emission Rates 12
Table 3-10: Annual Reduction in CO2 13
Table 3-11: GDP and Employment by Sector in Metro Vancouver 16
Table 3-12: GDP Increase 16
Table 3-13: Costs, Bus Operation Savings and Salvage Value (Undiscouted) 19
Table 4-1:Project Benefits and Costs in Present-Value 2021 Dollars 20
Table 4-2: Project BC and NPV 21
Table 5-1: Sensitivity Tests Summary ($2021 PV Millions) 25

Figures

Figure 1-1: SLS Project Alignment and Stations 1
Figure 2-1: Interpolation of Undiscounted Benefits 5
Figure 2-2: Discounted Benefits 6
Figure 3-1: Travel Time Reliability Example; Hypothetical Trips 9
Figure 3-2: Travel Time Standard Deviation Improvement 10
Figure 3-3: Access from Fleetwood – BAU Scenario 14
Figure 3-4: Access from Fleetwood – SLS Project Scenario 15
Figure 3-5: Diversion Due to Construction on Fraser Highway 18
Figure 4-1: Distribution of Benefits 22
Figure 4-2: Annual Distribution of Benefits and Costs in Present-Value 2021 Dollars 23

Appendix

A Logsum Method Explanation

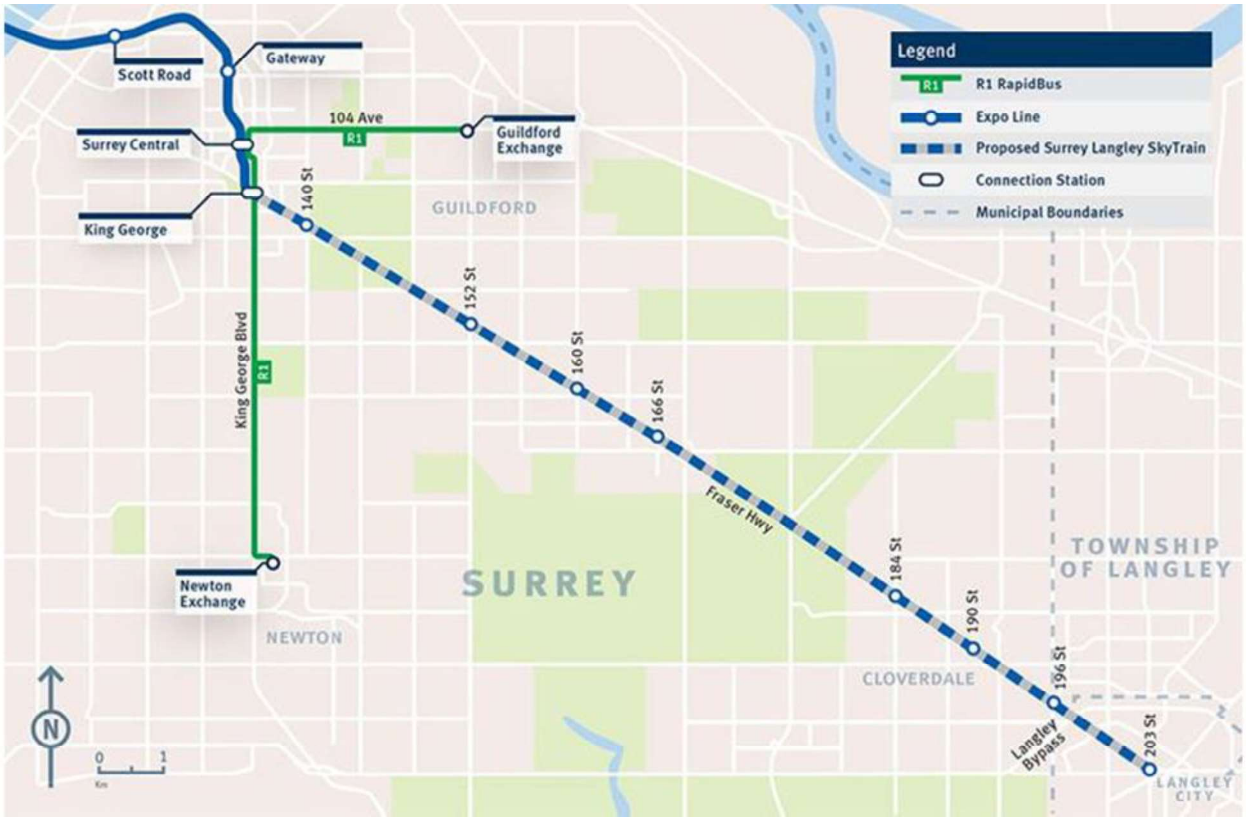
1. Introduction

Transportation Investment Corporation (TI Corp) required updated ridership and user benefits forecasts to support the business case for Surrey Langley SkyTrain (SLS) Expo Line extension from King George Station to Langley City Centre; i.e. the Project (see ***Error! Reference source not found.)***. TransLink's latest Regional Transportation Model (RTM 3.5) was the main tool used to develop forecasts for the Project.

This technical report presents updated economic lifecycle analysis outcomes and benefit-cost assessment prepared by McElhanney for the Project.

The project's ridership and other transportation related metrics, such as incremental transit trips and mode shares, are summarized in a separate report developed in March 2022: "Surrey Langley SkyTrain Business Case Update – Ridership Report"

Figure 1-1: SLS Project Alignment and Stations



1.1. BACKGROUND

In December 2018, the Mayor's Council directed TransLink to commence planning work for a SkyTrain extension along Fraser Highway. In 2019, TransLink embarked on an extensive study of potential SLS alignments and rapid transit technologies, culminating in a comprehensive business case that was approved by the Mayors Council in early 2020. McElhanney was part of the consulting team that assisted TransLink in delivering the original business case, specifically providing ridership and benefits forecasts. In July 2021, the Federal government pledged $1.3 Billion for building the complete extension to Langley City Centre.

TI Corp is responsible for delivering the updated business case. As such, TI Corp requires updated ridership and lifecycle economic forecasts based on the latest version of the Regional Transportation Model (RTM 3.5) and revised capital and operating costs.

2. The Regional Transportation Model (RTM)

The RTM is Metro Vancouver's official travel demand forecasting tool. It is developed and maintained by TransLink and is comprised of inter-connected mathematical models that are estimated from observed travel surveys, specifically the trip diary and screenline surveys. The RTM has historically been the main tool used by the region to forecast the impact of major transportation investments and policies such as: Port Mann/Highway 1 Upgrade, Broadway Subway Project (BSP), Transport 2050 and the Mobility Pricing Independent Commission (MPIC) study. Recently, the RTM was used to support the George Massey Tunnel Replacement business case which resulted in the selection of an eight-lane immersed tube tunnel option.

The RTM models typical fall weekday travel conditions for three distinct years – 2017 (base conditions), 2035 and 2050 (forecast years). Demographic inputs into the RTM, population and employment projections, are provided for each of those years directly by Metro Vancouver based on their latest Regional Growth Strategy which pivots from the most recent Census survey (2016). The model's transportation network provides a detailed representation of the region's current road and transit networks. Future road and transit upgrades assumed in the model for horizon years 2035 and 2050 are based on a list of major committed future projects as provided by the BC Ministry of Transportation and Infrastructure (BCMOTI), TransLink, and the region's municipalities.

As previously highlighted, forecasts for this study were developed using the latest version of the model, RTM 3.5. The previous business case used an earlier release, RTM 3.2. Both versions are structurally similar and generate comparable forecasts. Below are some key differences:

- RTM 3.5 includes more recent demographic forecasts and is better aligned with the latest regional growth strategy, Metro 2050, and municipal official community plans (OCPs).
- RTM 3.5 includes up-to-date road and transit network assumptions; for e.g. the eight-lane immersed tube George Massey crossing and the comprehensive RapidBus program.
- RTM 3.5 includes upgraded forecasting capabilities that model trip-chaining behaviour more realistically.
- RTM 3.5 includes several fixes to coding errors uncovered over the course of other transportation studies in the last two years.

- RTM 3.5 is programmatically more optimized and integrates seamlessly with TransLink's exploratory modelling analysis tool (EMAT) which is used to model risk and uncertainty in travel forecasts.

It is important to note that RTM 3.5 is based on pre-COVID-19 pandemic travel patterns. A such, base model assumptions do not account for potential long-term changes in post-pandemic travel behaviour (COVID-19 legacy) such as increase in tele-working and staggered work/school shifts. The COVID-19 legacy is discussed at a greater detail in the separate ridership memo.

2.1. MODEL VALIDATION

Prior to undertaking any forecasting analysis, it is important to confirm that the RTM's base year model (2017) validates well with observed travel behaviour, specifically transit ridership, traffic volumes and congestion in the study area. A well-validated model provides confidence in its ability to generate robust and reliable forecasts.

The model used for this study benefited from extensive validation and calibration effort undertaken for the previous business case as well as coding fixes to the RTM in the last two years. As such, no additional model validation or adjustment was required.

2.2. KEY MODELLING ASSUMPTIONS FOR ECONOMIC ANALYSIS

The RTM produces weekday daily travel demand forecasts by mode: auto, transit and active (walk and bike). Further, the model generates network-level forecasts for road traffic volumes and transit ridership by route for three distinct hours:

1) AM peak: 07:30 – 08:30
2) Mid-day: 12:00 – 13:00
3) PM peak: 16:30 – 17:30

To undertake the comprehensive economic analysis, various metrics from the RTM, such as travel time savings, are expanded to annual outputs and monetized using factors shown in *Table 2-1*.

Table 2-1: Economic Analysis Key Assumptions

Economic Analysis Assumptions and Inputs
Opening Year
2028
Project Evaluation Period; Source: BC MOTI Business Case Guidelines[1]
Construction Period + 25 Years (2028 to 2052)
Conventional Benefits Method
Consumer Surplus - LogSum (LS) and Rule of Half (ROH)
Dollar Year
2021 dollars
Inflation; Source: BC Stats[2]
BC Consumer Price Index (CPI)
Value of Time; Source: BC MOTI Business Case Guidelines

1 https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/planning/tools/default_values-benefit_cost_analysis.pdf
2 https://www2.gov.bc.ca/gov/content/data/statistics/economy/consumer-price-index

Economic Analysis Assumptions and Inputs	
Auto	Auto Occupant: $18.49 / hr in $2018
Truck	Truck Driver: $31.25 / hr in $2018
Transit	Transit User: $18.49 / hr in $2018
Vehicle Operating Cost; Source: BC Automobile Association Estimate	
Auto	$0.18/km in $2016
Light Truck (<3 axles)	$0.24/km in $2016
Heavy Truck (3+ axles)	$0.56/km in $2016
Value of Travel Time Reliability; Source: TransLink	
80% of Value of Time	
Discount Rate; Source: BC MOTI Business Case Guidelines	
Base	6% (real rate)
Discounting Reference Year	
2021 (i.e. discounting start in 2022 and onward)	
Expansion Factors (AM, MD, PM to Daily); Source: TransLink	
Single Occupancy Vehicles (SOV)	AM: 3.44, MD: 8.41, PM: 3.95
Higher Occupancy Vehicles (HOV)	AM: 1.51, MD: 8.58, PM: 5.32
Light Truck	AM: 3.59, MD: 5.63, PM: 6.17
Heavy Truck	AM: 4.88, MD: 5.43, PM: 6.36
Transit (Bus)	AM: 2.54, MD: 9.44, PM: 2.57
Transit (Rail)	AM: 2.53, MD: 9.54, PM: 2.92
Expansion Factors (Daily to Annual); Source: TransLink	
Auto (SOV and HOV)	335
Light Truck	313
Heavy Truck	276
Transit (Bus and Rail)	300
Transit Fares; Source: TransLink	
Three-zone fare system for SkyTrain and SeaBus; one-zone fare for buses. Fares in $2016	
Green-house Gas Emissions	
Emission Rate; Source: Metro Vancouver Emissions Model	Varies by year
Social Cost of Carbon (Monetize Emissions); Source: Environment Canada	$45/tonne ($2021) rising to $170/tonne CO2 by 2030 ($2030)
Traffic Collisions (Safety Analysis)	
Collision Rate; Source: BC MOTI Collision Rates[3]	Varies by facility
Collision Cost	Varies by collision type
Economic Agglomeration Benefits	
GDP by Industry ($2007); Source: City of Vancouver[4]	Varies by Industry
Employment by Industry; Source: Metro Vancouver Demographics	Varies by Industry

3 https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/transportation-planning/highway-safety-planning
4 https://vancouver.ca/files/cov/1-5-economic-structure-gdp-of-metro-vancouver.pdf

2.3. INTERPOLATION AND DISCOUNTING

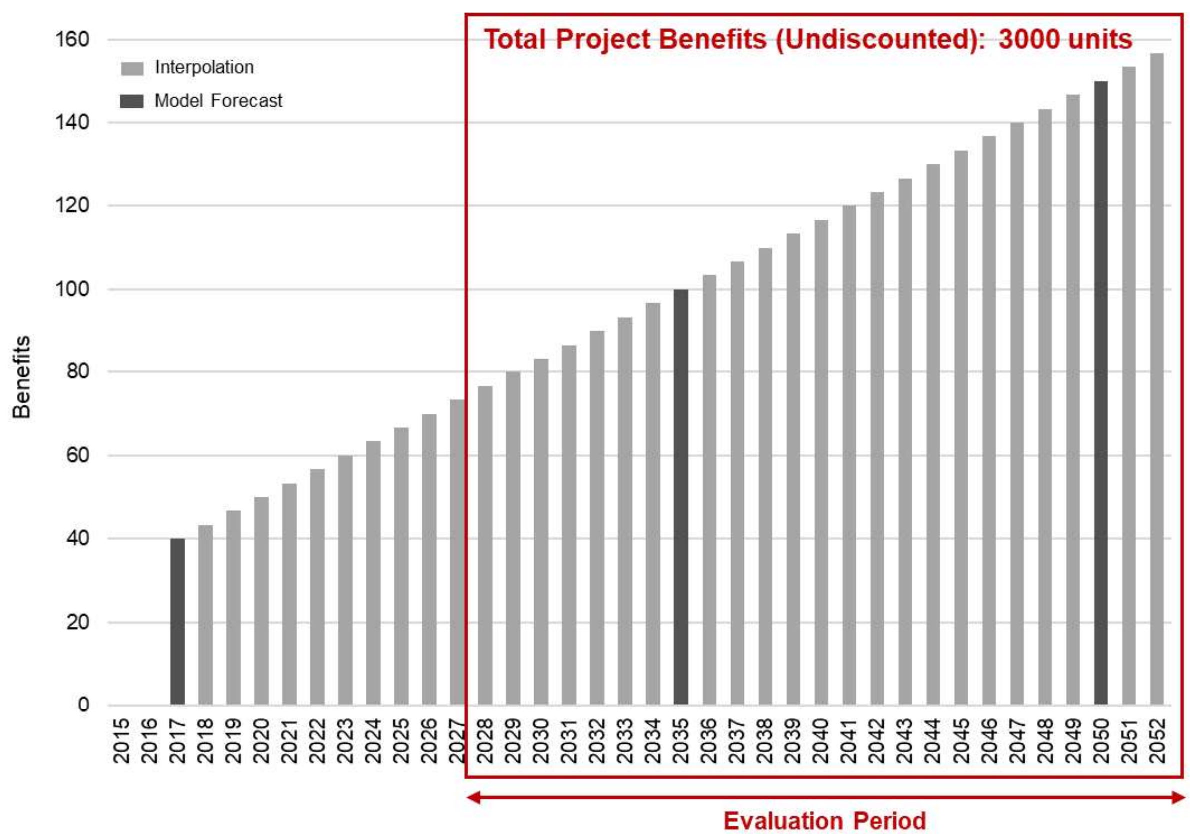
User benefits from the RTM were generated for two horizon years, 2035 and 2050. McElhanney also modelled a hybrid scenario using 2017 demographics and 2035 networks to establish a user benefit increment for the base year. For each of the model years, two model runs were undertaken to calculate user benefits:

- Business As Usual (BAU) Scenario: This scenario represents expected transportation conditions in the study area if the Project is not built.
- SLS Project Scenario: This scenario assumes the Project is built and operational.

Details on networks assumptions, auto and transit, as well as demographic inputs for both scenarios can be found in *Sections 3* and *4*, BAU and the Project descriptions, in the separate Ridership memo.

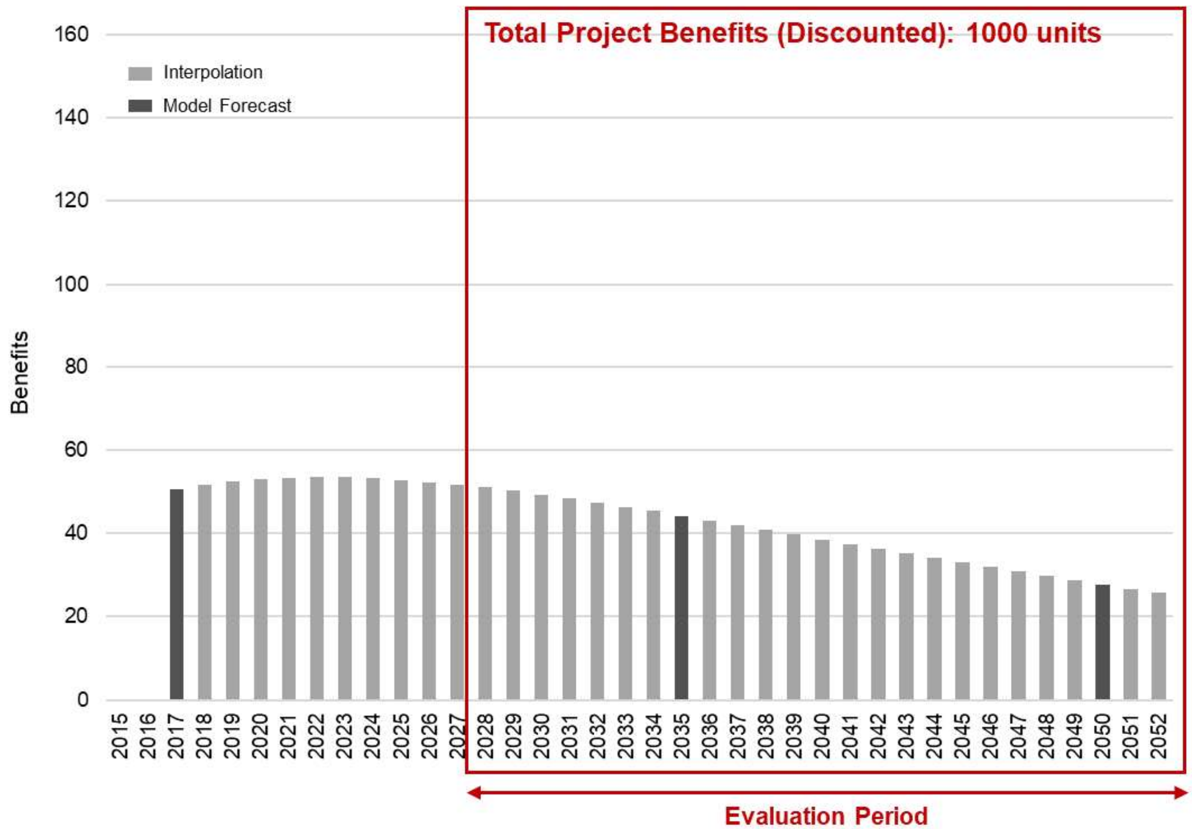
Simple linear interpolation is used to calculate undiscounted benefits for the opening year (2028) and each year within the project evaluation period, 2028 to 2052, as shown in the hypothetical example in *Figure 2-1*.

Figure 2-1: Interpolation of Undiscounted Benefits



The project's benefits and costs are discounted based on BC Ministry of Transportation and Infrastructure's standard, inflation-adjusted 6% rate as previously shown in *Table 2-1*. This generally means that benefits that accrue earlier in the project have a higher impact on the business case as shown in the hypothetical example in *Figure 2-2* showing the discounted benefits stream, assuming a discounting reference year of 2021.

Figure 2-2: Discounted Benefits



3. Methodology

This section discusses the methodology used to calculate transportation-related economic outcomes for the Project. These outputs are later used to calculate the benefit-cost-ratio (BCR) and net-present-value (NPV), two key economic indicators used for business case evaluation. Overall, four streams of benefits were considered for this project: conventional, wider, other and qualitative benefits, as shown in *Table 3-1*.

Table 3-1: User Benefit Streams

Benefits Stream	Account
Conventional	Regular travel time and cost savings (car and transit)
	Incremental transit fare revenue
	Goods movement travel time and cost savings (trucks)
Wider	Travel time reliability for all modes
	Safety (Reduction in collisions)
	Green-House Gas (GHG) emissions (CO2)
	Economic Agglomeration
Other	Commercial / Advertising Revenue
	Construction Impact

Benefits Stream	Account
Qualitative	Health
	Ambience
	Urban Realm

The **Conventional** benefits stream typically includes accounts that measure the first order impact of proposed transportation infrastructure, specifically travel time and cost savings. Conventional benefits are usually the prime reason that a transportation project is being considered[5].

The **Wider** stream includes 'indirect' or second-order benefits from the project that accrue over the lifetime of the project. Past business cases in the region typically included safety and GHG accounts. With improved data availability and analytical methods, more recent business cases added two more accounts to this stream: travel reliability and economic agglomeration.

The **Other** stream includes monetized accounts that do not fall in a specific category and that are not always considered in transportation economic welfare analysis such as advertising revenue and impact of construction activity in the corridor on travellers. These two, however, do have a measurable impact on the economic evaluation of this project.

The **Qualitative** stream includes important accounts that are difficult to quantify or monetize in the calculation of the BCR and NPV for various reasons such as:

- Complexity of measurement and availability of data.
- Lack of reliable research and methodologies for measuring those benefits.

The following subsections briefly describe the methodology adopted for calculating the accounts within each stream.

3.1. CONVENTIONALBENEFITS

This section describes accounts within the conventional benefits stream. Typically, conventional benefits account for approximately 75% to 85% of the total user benefits stream for major transportation projects.

Account 1: Travel Time and Cost Savings for Automobile and Transit Users

For large infrastructure projects, travel time and cost savings for regular trip-makers account for the largest share of the total benefits stream. While travel time savings are self-explanatory, travel cost savings / expenses can accrue due to:

- Reduction / increase in vehicle operating cost due to switching modes or change in distances travelled.
- Decrease / increase in transit fares.

Travel savings (time plus cost expressed in generalized cost minutes) were measured using consumer surplus theory[6]. Specifically, the logsum method was used to measure consumer surplus. The logsum metric includes both time and cost savings. For a theoretical background on logsum calculation, see

5 This is not necessarily the case for every project. For example, the prime benefit of improving a traffic signal operation project could be reducing collisions.

6 Consumer Surplus is the difference between the price that consumers are willing to pay currently and the savings achieved with improved service.

Appendix A. All the benefits generated in this account are measured in average weekday daily minutes for each of the RTM's model years (2017, 2035 and 2050). The benefits are monetized using BC Ministry of Transportation and Infrastructure's recommended value of time and annualized over the project lifetime as previously highlighted in *Table 2-1*. *Table 3-2* summarizes the forecast annual travel time savings for opening year 2028, 2035 and 2050 for the entire region.

Table 3-2: Auto and Transit Annual Travel Savings (Minutes)

Year	Transit Savings	Auto Savings
2028	428,008,000	114,960,000
2035	518,442,000	152,060,000
2050	694,514,000	261,776,000

Account 2: Incremental Fare Revenue

Incremental fare revenue is the additional transit revenue generated by a project resulting from a net increase in transit trips. All the benefits generated in this account are measured in average weekday daily incremental dollars for each of the RTM's model years (2017, 2035 and 2050). The benefits are annualized over the project lifetime using assumptions described in *Table 2-1*.

It is important to note that Account 1 (travel savings) includes additional transit fare costs incurred by users who switch to rail which requires up to a three-zone fare compared to bus which only requires a one zone fare across the region. Therefore, Account 2 is considered a 'tax transfer' whereby the additional revenue generated by TransLink from incremental fares paid by new transit users (and accounted for in Account 1) is 'transferred' back to society. *Table 3-3* summarizes the forecast annual incremental fare revenue (undiscounted) for opening year 2028, 2035 and 2050.

Table 3-3: Annual Incremental Fare Revenue in 2016 Dollars

Year	Incremental Fare Revenue ($2016)	Incremental Fare Revenue ($2021)
2028	$18,398,000	$20,293,000
2035	$21,738,000	$23,977,000
2050	$28,599,000	$31,545,000

Account 3: Goods Movement Travel Time and Cost Savings

Light and heavy truck travel time savings benefits are largely derived from auto users switching to transit, leaving more roadway capacity for goods movement, particularly on Fraser Highway and Highway 1. These directly relate to regional and national economic benefits including the economic competitiveness of the Greater Vancouver Gateway.

Truck benefits were also measured using consumer surplus theory. Specifically, the 'rule of half' method or ROH, was used to measure consumer surplus (see *Appendix A*). Since trucks are assigned to the network for three peak hours, AM, MD and PM, the benefits, which are measured in truck-minutes, were expanded and monetized to annual figures using factors shown in *Table 2-1*. *Table 3-4* summarizes truck travel time savings for opening year 2028, 2035 and 2050. Operating costs savings were omitted as those are negligible since trucks would largely use the same designated routes whether the Project is built or not.

Table 3-4: Annual Truck Travel Savings

Year	Truck Time Savings (minutes)
2028	2,851,000
2035	3,761,000
2050	6,357,000

3.2. WIDER BENEFITS

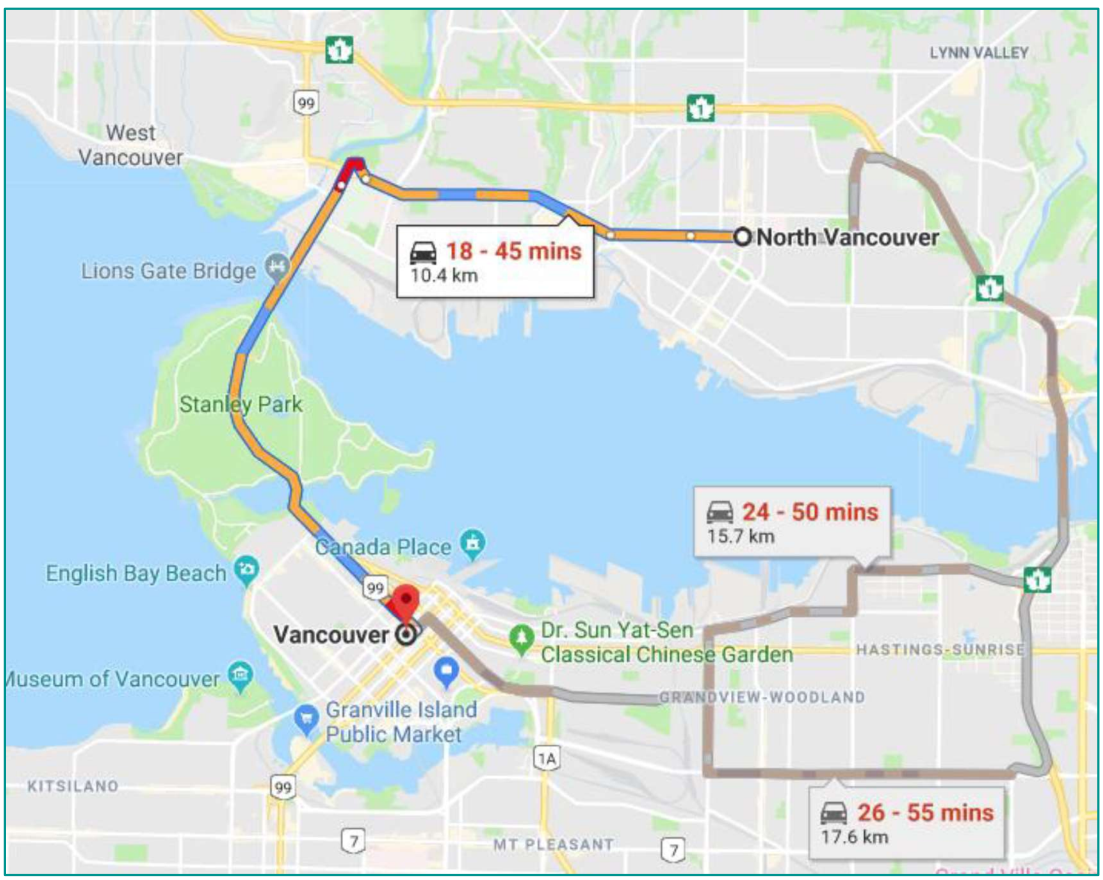
This section describes accounts within the wider benefits stream. Typically, wider benefits account for approximately 15% to 25% of the total user benefits stream.

Account 4: Travel Reliability

When a new infrastructure project is built, average travel times for some travellers decrease. This improvement is already accounted for in the conventional benefits. Another potential benefit of the project is an overall increase in travel reliability. In fact, one of the most attractive features of rapid transit is its perceived reliability and on-time performance relative to road-based modes, i.e., cars and buses.

Figure 3-1 shows a hypothetical trip from North Vancouver to downtown across the Lions Gate bridge. According to Google Maps, this trip takes between 18 and 45 minutes in the morning on a typical weekday.

Figure 3-1: Travel Time Reliability Example; Hypothetical Trips



This wide range represents the variable nature of travel times due to:

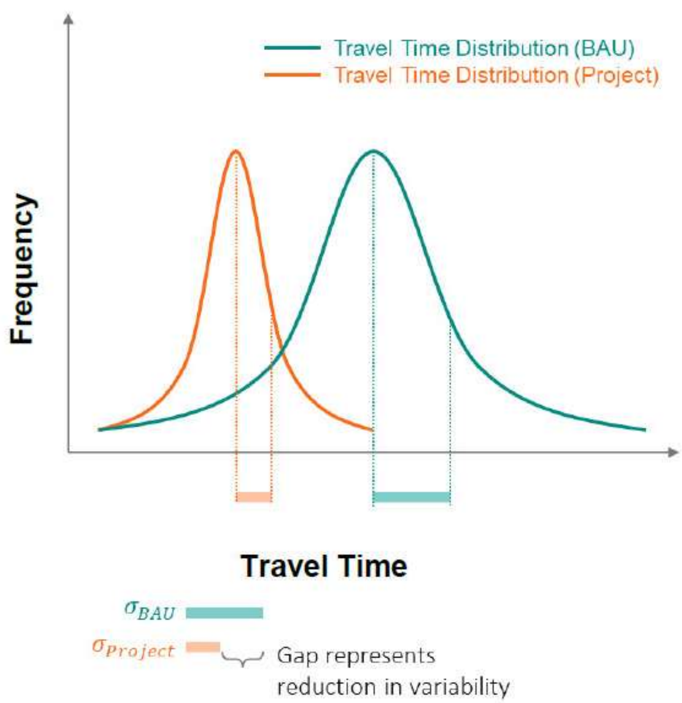
- Demand variability: For example, traffic is usually higher on Tuesday than Monday.
- Accidents or vehicle breakdowns.
- Weather and visibility.

Those factors can influence congestion levels significantly at capacity constrained sections of the road. Given the random nature of congestion, travellers include 'buffer time' in their schedule especially for important trips such as for a work meeting or a doctor's appointment. In the example above, some people will leave their home 45 minutes earlier to guarantee reaching their destination on time even if the trip takes 25 minutes on average. If travel to downtown was more reliable, a person could have used that extra buffer time to perform other activities, such as exercising, spending time with family or shopping. Reliable travel times allow people to use their time more freely and efficiently.

For the goods movement sector, reliability improvements reduce economic inefficiency in the supply chain which sometimes arise from trucks not making their deliveries within their assigned time slot, resulting in additional receiver costs and potential penalties to delivery businesses. For example, a truck may have a half hour window to deliver goods to a warehouse where staff have been scheduled to help unload the goods. If the truck is late, then these staff sit idle, and possibly have to accrue overtime hours to unload the truck at a later time incurring additional business costs that reduce business competitiveness.

Several business case guidelines[7] account for reliability within the benefits stream using the travel time standard deviation measure as shown in *Figure 3-2*. Furthermore, recent business cases in the region included the reliability account – e.g. the Broadway Subway Project and the George Massey Tunnel Replacement.

Figure 3-2: Travel Time Standard Deviation Improvement



7 MetroLinx Business Case Guidelines: 'Business Case Manual Volume 2' p100 - 102. http://www.metrolinx.com/en/regionalplanning/projectevaluation/benefitscases/Metrolinx-Business-Case-Guidance-Volume-2.pdf

Auto and Truck Reliability

Improvements in car and truck travel time reliability for the Project business case is measured using a model developed by TransLink's Forecasting team that predicts the standard deviation of travel time in minutes as a function of congestion between various origin-destination pairs from the RTM. *Table 3-5* summarizes auto and truck reliability benefits for opening year 2028, 2035 and 2050.

Table 3-5: Annual Auto & Truck Travel Time Reliability Savings (Minutes)

Year	Auto	Truck
2028	39,926,000	6,863,000
2035	55,595,000	9,678,000
2050	127,313,000	20,399,000

Transit Reliability

Reliability of transit service can be quantified differently depending on service type[8]. For infrequent services (i.e. headways longer than 10 minutes) on-time arrival at a stop is the most important factor. In those cases, people usually 'time' their wait ahead of the bus's scheduled arrival time at a specific stop.

For frequent services (headways less than 10), on-arrival time becomes less important. Instead, in-vehicle time becomes a more critical factor. In-vehicle time for buses is a function of congestion on the road and the level of boarding and alighting activity at stops.

For this study, the project team adopted the second approach, i.e. improvement in in-vehicle travel time reliability (i.e., reduction in standard deviation) as a result of having more reliable SkyTrain service compared to a limited-stop bus service along Fraser Highway[9]. *Table 3-6* summarizes transit reliability benefits for opening year 2028, 2035 and 2050.

Table 3-6: Annual Transit Travel Time Reliability Savings (Minutes)

Year	Transit
2028	19,699,000
2035	27,861,000
2050	46,696,000

Account 5: Safety (Reduction in Collisions)

Generally, more vehicle volume leads to more accidents on the road. Accidents have both social and economic, or loss of productivity, impacts. If the Project is built, a segment of auto users will switch to transit, resulting in fewer accidents over the lifetime of the project.

Modelled decrease in vehicle kilometers travelled (VKT) from the RTM was used to calculate the reduction in collisions by three types: property damage only, injury and fatal. The VKT metric by link was multiplied by average five-year collision rates by facility type published by BC MOTI. Total reduction in collisions was then monetized using the rates shown in *Table 3-7* as per BC MOTI's Business Case Guidelines.

8 MetroLinx Business Case Guidelines p100 – 102
http://www.metrolinx.com/en/regionalplanning/projectevaluation/benefitscases/Metrolinx-Business-Case-Guidance-Volume-2.pdf
9 TransLink provided estimates of existing travel time standard deviation on Fraser Highway routes (502 and 503) which were used to estimate variability for the limited-stop service assumed in the BAU scenario.

Table 3-7: Cost of Collision by Type

Collision Type	Cost($2018)	Cost($2021)
Property Damage	$8,087,000	$8,508,000
Injury	$303,000	$318,000
Fatal	$13,500	$14,200

Table 3-8 summarizes the expected reduction in total collisions for opening year, 2028, 2035 and 2050. This reduction would support the City of Surrey's Vision Zero Safe Mobility Plan which envisions "zero people killed or seriously injured on our roads".

Table 3-8: Annual Reduction in Number of Collisions

Year	Reduction in Collisions
2028	50
2035	60
2050	70

Account 6: Greenhouse Gas (GHG) Emission Reduction

The transportation sector is one of the leading emitters of green-house gases. According to Metro Vancouver, 37% of the region's GHG's come from transportation sources[10]. While the fuel efficiency of gasoline-powered vehicles has improved substantially, driving is still a major source of carbon emissions. Transit improvements, such as building a new rail line reduces emissions since people substitute their cars for transit. The reduction is even higher if people switch to transit for commuting trips since emission rates are higher in congested conditions compared to cruising speeds. Further, the SkyTrain system is electrified and the electricity in British Columbia is largely derived from renewable sources such as hydro dams which have minimal emissions during operations.

For the Project business case, GHG emissions are expected to decrease as people switch from cars to rail. GHG reduction in CO2 equivalent (CO2e) emissions, were calculated by converting VKT reduction to CO2e using rates (grams of equivalent CO2) sourced from Metro Vancouver's emissions model as shown in *Table 3-9*. Metro Vancouver modelled two scenarios in 2035; a BAU scenario that assumes baseline electric vehicle (EV) penetration and an 'Aggressive' scenario that incorporates higher EV fleet penetration. For the Project business case, our team used BAU emission rates for 2035 and 'Aggressive' rates for 2050.

Table 3-9: Metro Vancouver $CO2_e$ Emission Rates

Year	Auto (g/VKT)	Light Truck (g/VKT)	Heavy Truck (g/VKT)
2017	248	328	1,132
2035 (Base)	152	238	1,050
2035 (Aggressive) used for 2050 RTM Scenario	91	203	1,050

10 http://www.metrovancouver.org/metro2040/environment/reduce-ghgs/ghg-emissions/Pages/default.aspx

Table 3-10 summarizes the modelled expected reduction in tonnes of $CO2_e$ for opening year, 2028, 2035 and 2050.

Table 3-10: Annual Reduction in CO2

Year	Reduction in $CO2_e$ (tonnes)
2028	14,100
2035	13,500
2050	9,700

Another source of $CO2_e$ emission is related to construction, specifically cement production for concrete structures. Those were calculated by multiplying estimates of concrete quantities[11] (m^3) for stations, guideways and other structures with standard concrete production emission rates[12].

CO_2 emission reductions were monetized based on the current BC carbon price of $45/tonne which will rise to the federally mandated carbon price of $170/tonne[13] by 2030[14]

Account 7: Economic Agglomeration

The final wider benefit account included in this business case is economic agglomeration. Stated simply, agglomeration is the increase in gross domestic product (GDP) for different economic sectors resulting from increased proximity among business clusters in a defined region. For example, if the Project is built, businesses in the Fleetwood area will have better access to financial services in Surrey Central, thus reducing business costs and improving overall efficiency and productivity as shown in the transit accessibility maps to/from Fleetwood, *Figures 3-3* and *3-4*.

11 Concrete quantity based on estimates provided from the previous business case
12 https://www.cement.org/docs/default-source/th-paving-pdfs/sustainability/carbon-foot-print.pdf
13 Source: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/annex_pricing_carbon_pollution.pdf
14 This price occurs in year 2030 and is equivalent to $142 in 2021 dollars assuming a 2% inflation rate. Beyond 2030 it is assumed that this price escalates with inflation.

Figure 3-3: Access from Fleetwood – BAU Scenario

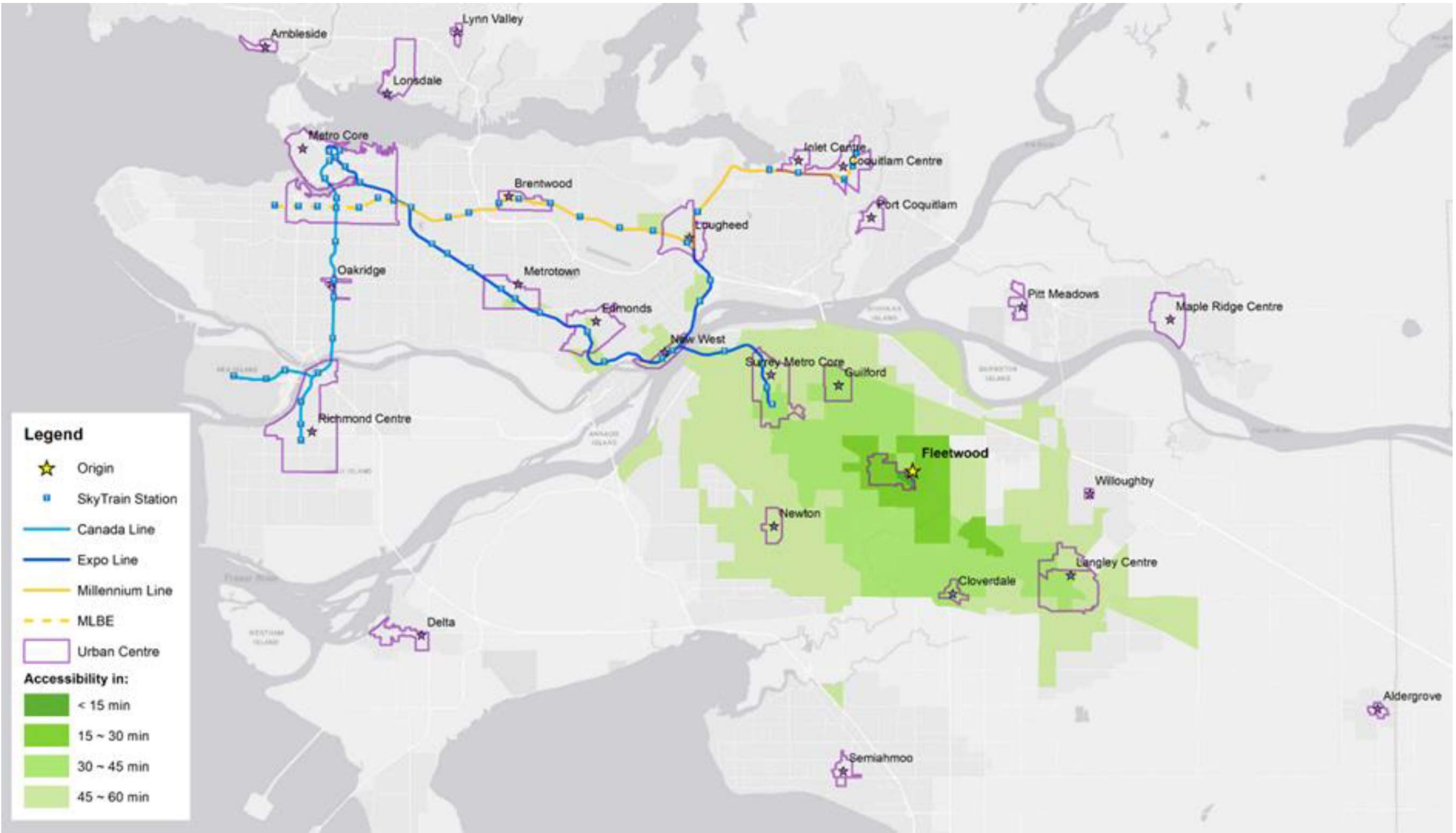
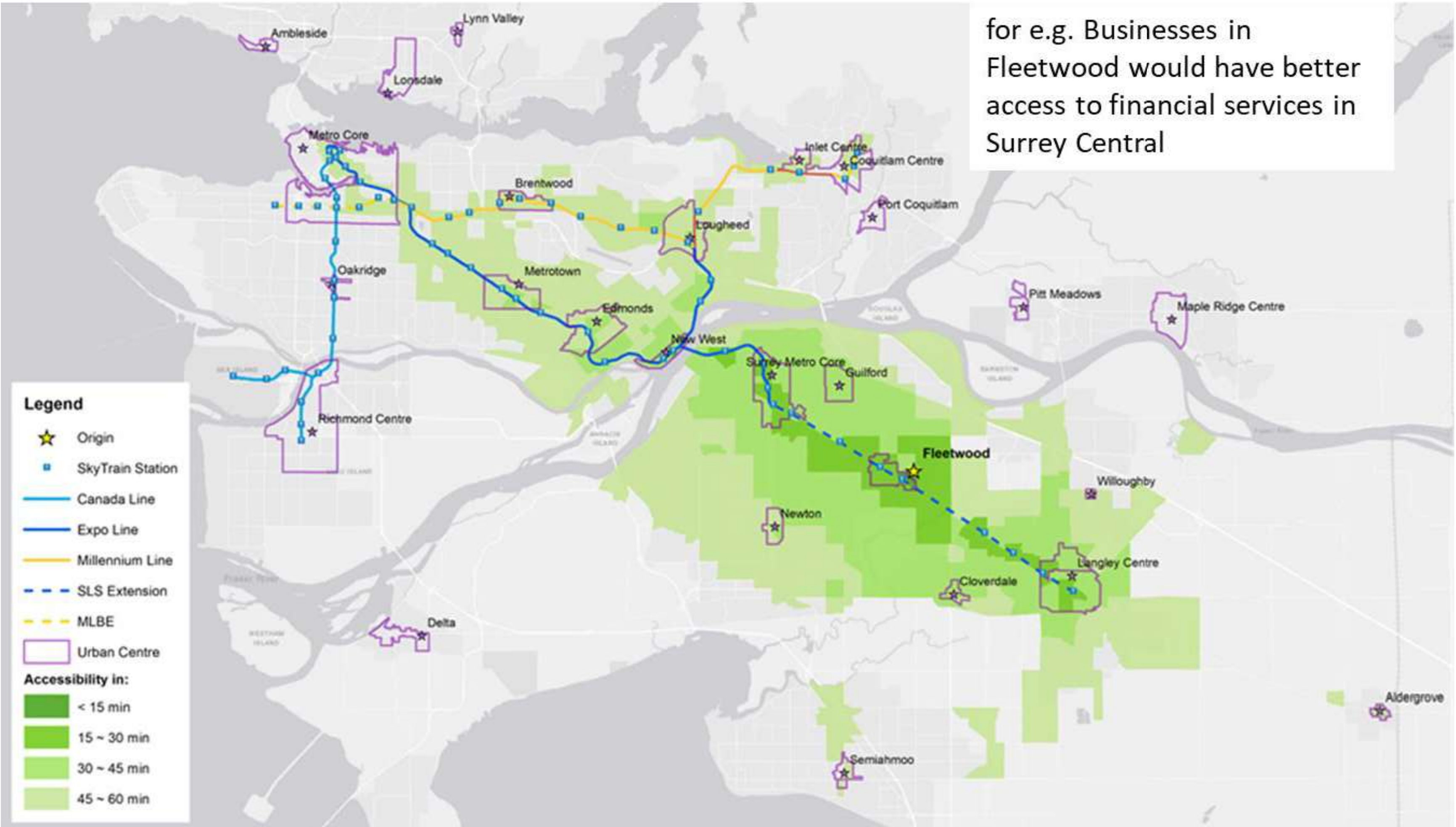


Figure 3-4: Access from Fleetwood – SLS Project Scenario



Agglomeration benefits are usually the largest component of a transportation project's macro-economic benefits and are well documented in transport economics research[15]. Only 'static' agglomeration, i.e. productivity increase resulting from clustering for the existing labour force, is included in the Project business case. Labour supply changes induced by the Project, i.e. in-migration to Metro Vancouver, is not considered given that the RTM assumes fixed demographic forecasts.

Agglomeration benefits for the Project business case were calculated using the UK Department of Transport TAG (Transport Analysis Guidance)[16] which provides elasticity estimates (or percent change) in GDP by different sectors as a result of increased proximity, or percent reduction in travel time.

Agglomeration benefits were limited to the City of Surrey, City and Township of Langley, the Three Municipalities, since clustering effects diminish the further businesses are located apart.

Table 3-11 summarizes the GDP and employment information used to calculate agglomeration benefits.

Table 3-11: GDP and Employment by Sector in Metro Vancouver

Employment Sector	Percent of Metro Vancouver GDP	GDP ($2007 Billion)	2017 Employment (Metro Vancouver)	GDP per worker ($2007)
Construction & Manufacturing	17%	23	200,200	$ 114,900
Finance, Insurance and Real Estate	31%	42	106,700	$ 393,800
Transportation, Communication, Utilities and Wholesale	13%	18	143,000	$ 125,900
Retail	6%	8	153,000	$ 52,300
Business & Other Services	10%	14	261,100	$ 53,600
Accommodation, Food, Information and Cultural	8%	11	192,900	$ 57,000
Health, Education and Public Administration	15%	20	298,800	$ 66,900

Table 3-12 summarizes incremental GDP benefits (undiscounted) for the region for opening year, 2035 and 2050.

Table 3-12: GDP Increase

Year	GDP Gain (2007)	GDP Gain (2021)
2028	$16,218,000	$19,948,000

15 CD Howe Institute "Cars, Congestion and Costs: A New Approach to Evaluating Infrastructure Investment". p8 - 14
16 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/554790/webtag-productivity-impacts-tag-unit-a24.pdf

2035	$21,250,000	$26,138,000
2050	$33,056,000	$40,659,000

3.3. OTHER BENEFITS

The 'Other' benefits stream includes monetized accounts that do not fall in a specific category and that are not always considered in transportation economic welfare analysis such as advertising revenue and impact of construction activity. For the Project business case, two accounts are included in the 'Other' stream; commercial revenue and construction impact.

Account 8: Commercial Revenue

This account includes estimates of revenue generated by commercial/retail activity such as advertising at the new stations over the project evaluation period; 2028 to 2052. The estimates were provided directly by TI Corp and are approximately [redacted] in 2021 dollars (undiscounted) over the 25-year evaluation period.

Account 9: Construction Impact

Construction activity can have short-term negative impacts on businesses and residences within the project area. These can be due to temporary road closures, local access restrictions or elevated noise levels.

The RTM was used to calculate some of the disbenefits associated with the Project construction activity, namely increase in vehicle travel times and costs due to reduction in the number of lanes and posted speed along Fraser Highway. The list below summarizes temporary changes to the configuration of Fraser Highway during construction:

1) Reduction by one general purpose lane along Fraser Highway in both directions between Whalley Street in Surrey to 196A Street in Langley.
2) Posted speed changes to following sections:
    a. Between Surrey Central and 168th Street: Speed reduced from 60 kph to 40 kph.
    b. Between 168th Street and 182nd Street: Speed reduced from 70 kph to 50 kph.
    c. Between 182nd Street and Highway 10: Speed reduced from 60 kph to 40 kph.

Our team assumed that the above changes would span one full year, 2026. In reality, the temporary corridor reconfiguration will likely occur at select road sections at different times depending on construction method and schedule. As such, the construction impacts should be considered a high-level estimate with some level of uncertainty especially that they do not include other impacts related to access to the corridor's businesses.

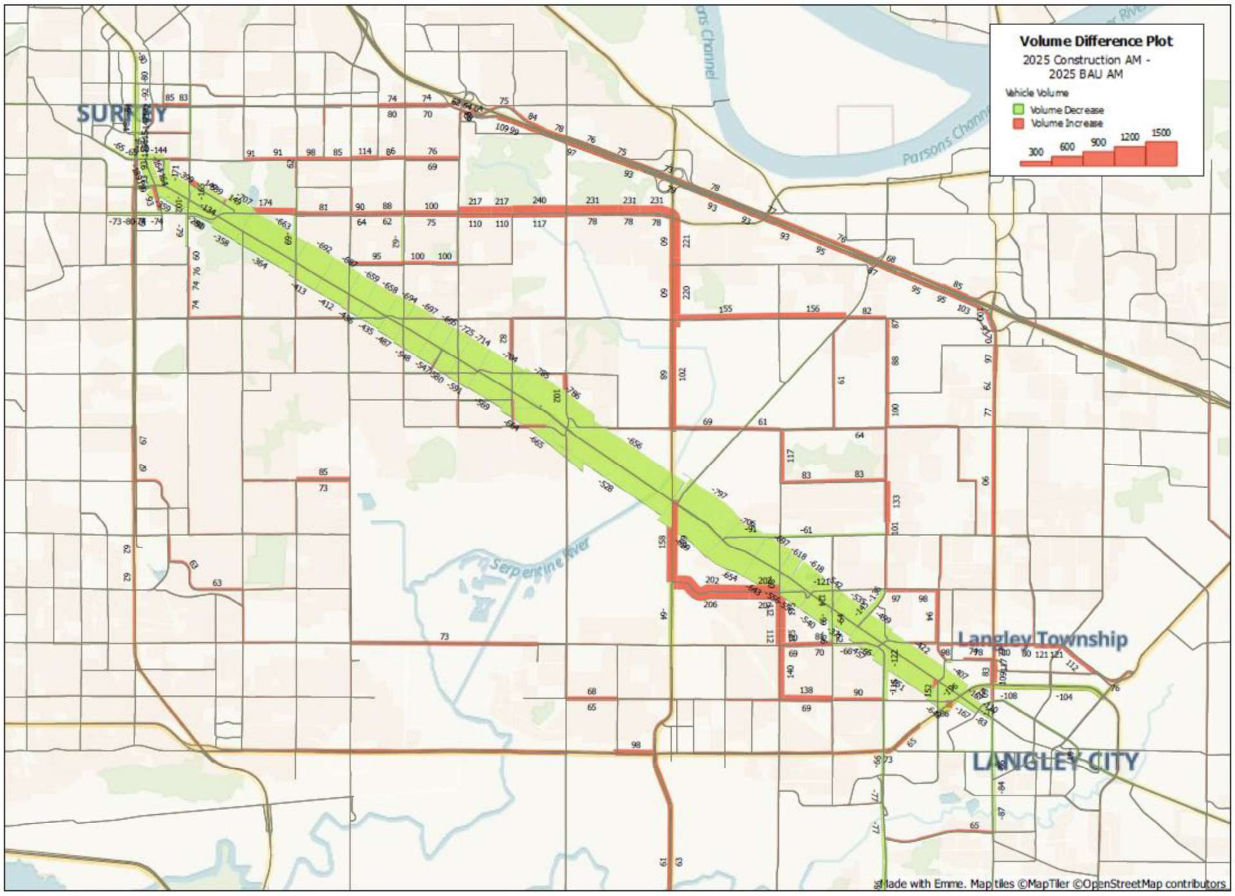
Figure 3-5 shows the modelled morning peak traffic diversion due to construction activity[17]. Traffic from Fraser Highway is expected to disperse throughout the network of the Three Municipalities, mainly diverting to the following routes:

- Highway 15 and 96th Avenue.
- Highway 1.
- Highway 10 and King George Boulevard.

17 To model 2026 conditions in the RTM, we developed custom demographics inputs that were interpolated from the available 2017 and 2035 demographics file. We also used the 2035 network as a proxy for 2026 networks with the key assumption of reverting the George Massey Tunnel to current conditions.

The estimated construction impacts, mainly travel time and vehicle operating cost disbenefits (negative benefits), are **$41,000,000** in 2021 dollars (undiscounted).

Figure 3-5: Diversion Due to Construction on Fraser Highway



3.4. QUALITATIVE BENEFITS

The ‘Qualitative’ stream includes accounts that provide benefits/disbenefits but are not quantified in the business case for various reasons such as:

- Complexity of measurement.
- Lack of reliable research and data sources for measuring those benefits.

Specifically, three qualitative accounts are briefly discussed in this section:

- Health Benefits.
- Urban Realm.
- Ambience.

Health Benefits

Overall, the Project will likely increase physical activity as a result of people switching from cars to transit modes, which on average require more walking to access stations and bus stops.

While the project team acknowledges that transit projects will generate some health benefits, it was ultimately decided to exclude them due to the complexity of assigning health-related monetary value and lack of extensive research on an appropriate methodology to do so. While a handful of methods to monetize health benefits exist internationally, their relevance to the Metro Vancouver context is unclear.

Ambience

Journey ambience includes many factors relating to transit service quality and comfort not quantified through journey time, reliability or crowding. They relate to 'softer' factors which impact perceptions of travel, such as the cleanliness of transit services, provision of information and wayfinding, improved pedestrian walkways or bicycle paths, or the security of station stops and services. While some recent research provides methods to quantify ambience it is generally difficult to do so. For example, the perception of safety at a SkyTrain station can vary significantly from one person to the other. Note that a portion of ambience benefits associated with SkyTrain service are implicitly accounted for in the transit travel savings account (see *Appendix A* for more information).

Urban Realm

Urban realm includes features such as high-quality sidewalks, landscaping and street art around bus or rail stations. Urban realm benefits were not included since those are usually associated with surface-transit projects such bus rapid transit (BRT) and light rapid transit (LRT). Further, methodologies to quantify urban realm impacts, including Metro Vancouver specific stated-preference surveys, are still being developed and refined.

3.5. COSTS, BUS SAVINGS AND SALVAGE VALUE

Project costs are comprised of two components:

1) Capital Costs: These include construction costs, property acquisition, rail car purchase, contingency and other costs.
2) Operating Costs: These costs cover the operations and maintenance phase of the Project over the evaluation period as well as other related costs such as staff training.

In addition to costs, the Project will result in bus operation savings due to a reduction in bus service along Fraser Highway.

Salvage value is the residual value of major project assets at the end of the evaluation period. These include the extension's guideway, rail vehicles, stations and other assets which have lifecycles longer than the 25-year evaluation period.

Costs, bus savings and salvage value, were provided to McElhanney by TI Corp and are summarized in *Table 3-13* and later used to conduct the economic evaluation, i.e. calculate the project BCR and NPV.

Table 3-13: Costs, Bus Operation Savings and Salvage Value (Undiscounted)

Account	Value ($2021) Millions	
Capital Cost	$	[redacted]
Operating Costs	$	[redacted]
Bus Operation Savings	$	[redacted]
Other Revenue	$	[redacted]
Salvage Value	$	[redacted]

4. Project Benefits and Life Cycle Economic Outcomes

This section summarizes the total project benefits, costs and economic outcomes specifically, the project BCR and NPV.

4.1. BENEFITS AND COSTS SUMMARY

Table 4-1 summarizes the total project present value benefits and costs. As expected, most of the benefits are derived from the conventional streams, auto and transit travel savings. Transit travel savings has the largest share of the benefits, about 55%, as expected.

About [redacted] of total project costs are comprised of capital costs, also as expected.

Table 4-1:Project Benefits and Costs in Present-Value 2021 Dollars

Stream	Account	Present Value in $2021 Million	
Costs	Capital Cost	$	[redacted]
	O&M Cost	$	[redacted]
	Salvage Value	*$*	[redacted]
	Total Costs	**$**	**3,048**
Benefits	Transit Travel Savings	$	1,609
	Auto Travel Savings	$	496
	Reliability	$	259
	Wider Economic Benefits	$	254
	Fare Revenue	$	225
	Collision Cost Savings	$	137
	Bus O&M Savings	$	86
	Truck Travel Savings	$	40
	Other Revenue	$	8
	GHG Emissions Savings	$	14
	Construction Delay	*$*	*-31*
	Total Benefits	**$**	**3,097**

4.1. ECONOMIC OUTCOMES

Table 4-2 summarizes the project benefit-cost-ratio and net-present-value. Overall, the Project generates good economic value as indicated by the positive NPV and the BCR exceeding 1.0. *Figure 4-1* provides a waterfall diagram showing the contribution of benefits by type to the total project benefits illustrating the significant contribution from transit travel time savings. *Figure 4-2* then shows the annual discounted costs and benefits over the entire project lifecycle illustrating the significant expenditures during the construction phase and the benefits derived during the operational phase.

Table 4-2: Project BC and NPV

Lifecycle Economic Indicator	Value
Net Present Value ($2021 Million)	$49
Benefit Cost Ratio	1.02

Figure 4-1: Distribution of Benefits

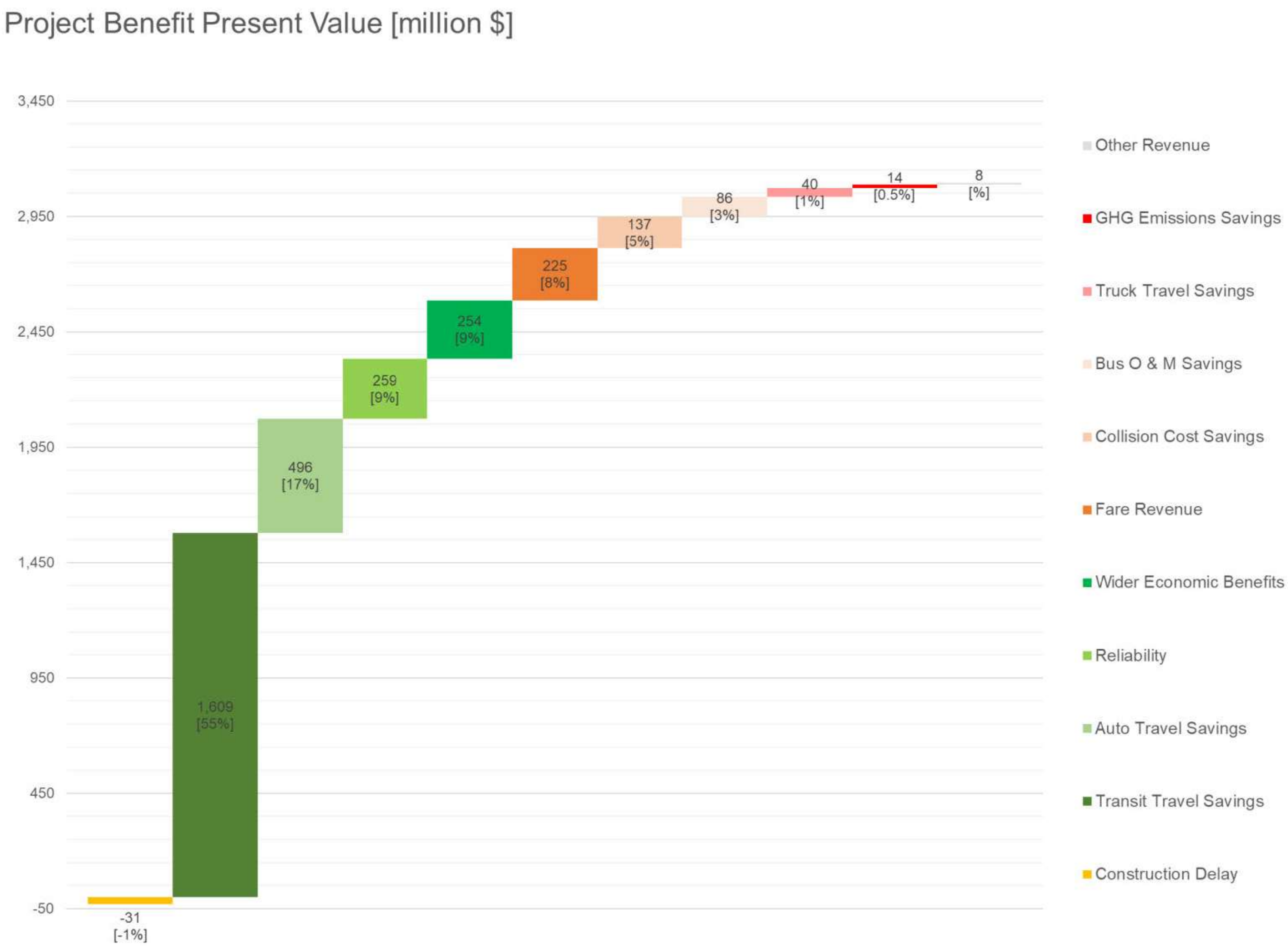
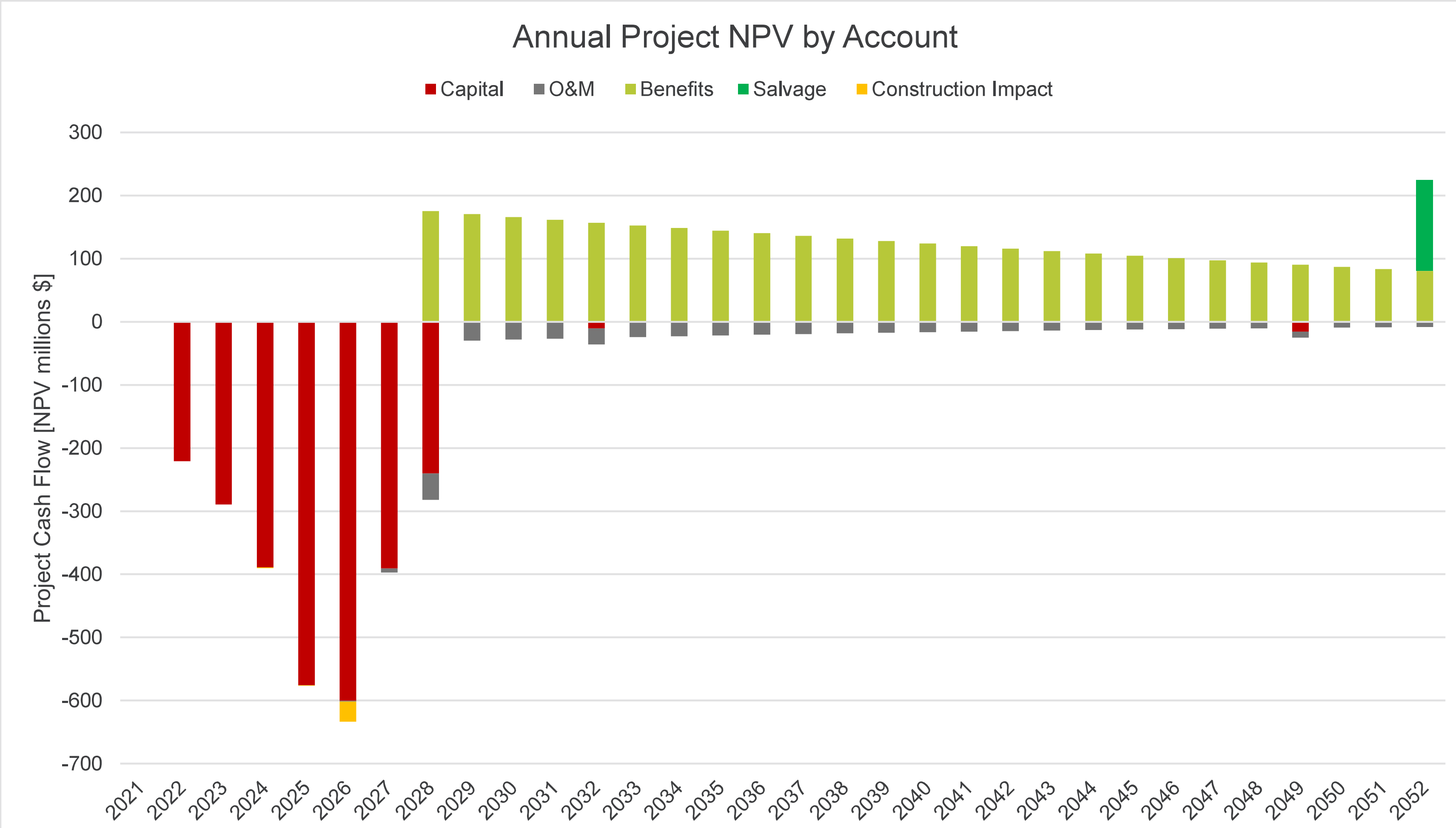


Figure 4-2: Annual Distribution of Benefits and Costs in Present-Value 2021 Dollars



5. Economic Analysis Sensitivity Outputs

Sensitivity analysis is the process of varying an analysis input and determining the magnitude and effect on the analysis outputs. The results of a sensitivity analysis provide useful information to stakeholders on the impact of changes to key variables on the project's economic outcome and, more importantly, quantify possible downside economic outcomes.

As per BC MOTI's business case guidelines[18], sensitivity analyses were conducted for the following variables:

- Discount Rate: +/- 2%
- Capital Costs: +/- 10% and +/- 25%
- Annual Growth in SLS Ridership: +/- 0.5%

Table 5-1 summarizes the economic outcomes for each sensitivity test listed above. Below is a summary of key observations:

- Across all categories, the project's BCR ranges between 0.81 and 1.31
- Of the three variables, variation in discount rate has the largest impact on the BCR

Assuming slower growth than expected, the BCR decreases to 0.86. This outcome provides a downside indicator if forecast ridership growth in the corridor does not materialize, either due to slower pace of redevelopment or other causes, such as permanent changes to travel behavior post the COVID-19 pandemic.

Under certain conditions, there is risk that the project costs would outweigh its benefits. However, the current project evaluation framework and monetization of benefits does not include other non-quantifiable benefits such as health effects, access to jobs and affordable housing for lower income households, increased development, community livability and other equity impacts. Considering these, the project still presents a viable business case that will provide a broad range of community and regional benefits.

18https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/planning/tools/benefit_cost_analysis_guidebook.pdf

Table 5-1: Sensitivity Tests Summary ($2021 PV Millions)

Account	Base	Discount Rate		Capital Costs				Ridership Growth	
		-2% (4%)	+2% (8%)	-25%	-10%	+10%	+ 25%	- 0.5%	+ 0.5%
Construction Cost	$ [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]
O & M Cost	$ [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]
Salvage Value	$ [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]	[redacted] [redacted]
Total Costs	**$ 3,048**	**$ 3,338**	**$ 2,786**	**$ 2,400**	**$ 2,789**	**$ 3,307**	**$ 3,695**	**$ 3,048**	**$ 3,048**
Transit Travel Savings	$ 1,609	$ 2,251	$ 1,177	$ 1,609	$ 1,609	$ 1,609	$ 1,609	$ 1,387	$ 1,867
Auto Travel Savings	$ 496	$ 704	$ 357	$ 496	$ 496	$ 496	$ 496	$ 388	$ 644
Reliability	$ 259	$ 372	$ 185	$ 259	$ 259	$ 259	$ 259	$ 193	$ 359
Wider Economic Benefits	$ 254	$ 359	$ 184	$ 254	$ 254	$ 254	$ 254	$ 205	$ 315
Fare Revenue	$ 225	$ 314	$ 165	$ 225	$ 225	$ 225	$ 225	$ 198	$ 257
Collision Cost Savings	$ 137	$ 189	$ 102	$ 137	$ 137	$ 137	$ 137	$ 124	$ 138
Bus O & M Savings	$ 86	$ 117	$ 64	$ 86	$ 86	$ 86	$ 86	$ 86	$ 86
Truck Travel Savings	$ 40	$ 56	$ 29	$ 40	$ 40	$ 40	$ 40	$ 31	$ 51
Other Revenue	$ 8	$ 12	$ 6	$ 8	$ 8	$ 8	$ 8	$ 8	$ 8
GHG Emissions Savings	$ 14	$ 20	$ 10	$ 14	$ 14	$ 14	$ 14	$ 11	$ 18
Construction Delay	$ (31)	$ (33)	$ (29)	$ (31)	$ (31)	$ (31)	$ (31)	$ (31)	$ (31)
Total Benefits	**$ 3,097**	**$ 4,361**	**$ 2,252**	**$ 3,097**	**$ 3,097**	**$ 3,097**	**$ 3,097**	**$ 2,602**	**$ 3,713**
BCR	**1.02**	**1.31**	**0.81**	**1.29**	**1.11**	**0.94**	**0.84**	**0.85**	**1.22**
NPV	**$ 49**	**$ 1,023**	**$ (534)**	**$ 696**	**$ 308**	**$ (210)**	**$ (598)**	**$ (446)**	**$ 666**

Appendix A
Logsum Method Explanation

Logsum Method Explanation

The logsum is a composite measure of the utility[19] of all travel alternatives between a given origin and destination pair. For the benefits analysis, the natural logarithm of the logit mode choice model denominator is divided by the in-vehicle travel time coefficient to convert the output to units of time in minutes.

The following example will be used to demonstrate the concept of the logsum measure.

In **Figure A- 1**, 100 people want to travel from Surrey to Langley. A mode choice model, which is the third step of the four-step model, is used to split the demand between auto and transit.

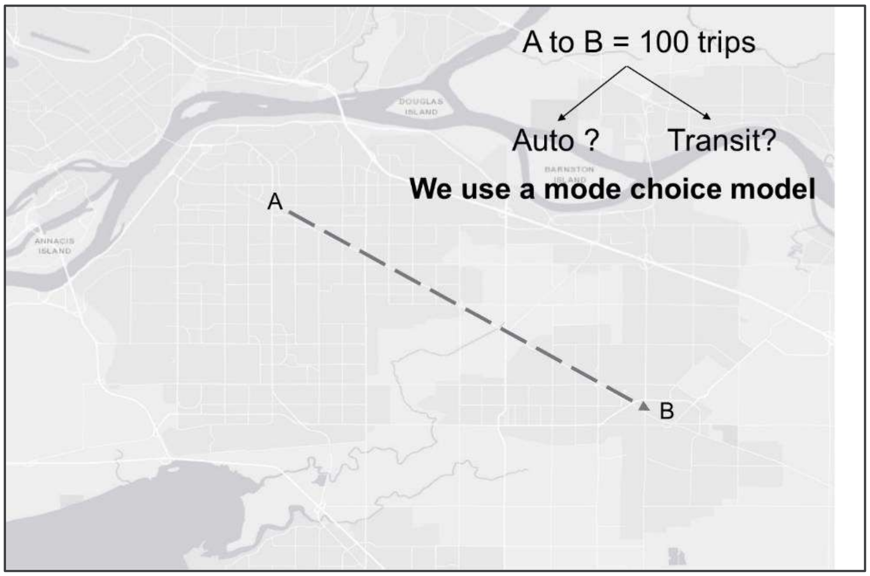


Figure A- 1: Logsum 'Hypothetical Trip' Example

Table A- 1 shows a hypothetical mode choice model with a simple utility formulation:

U_{mode} = B1xtime$_{mode}$ + B2xcost$_{mode}$ and

parameter estimates B1 (time coefficient) = -0.05 and B2 (cost coefficient) = -0.2.

Table A- 1: Mode Choice Model Example

Mode	Travel Time (min)	Travel Cost ($)	Utility equation	Utility value	Demand
Auto	20	$2.00	B1*time + B2*cost	-1.40	74
Transit	45	$1.00	B1*time + B2*cost	-2.45	26

As expected, most users choose auto. The logsum, or composite utility of travel, between A and B is calculated as follows:

Logsum = log((expUtility$_{Auto}$) + (exp^Utility$_{Transit}$)) = -1.10

19 Utility is a term used by economists to describe the measurement of "desirable-ness" that a consumer obtains from any good (or service).

The logsum value, -1.10, is converted to minutes by dividing it by the coefficient of time B1. Thus -1.10 units of utility is equal to 22 minutes.

A new rail line is proposed between A and B and is expected to reduce transit travel times by 15 minutes as shown in **Table A- 2**. Based on this information, the updated logsum value between A and B increases by 0.35 units, from -1.10 to -0.85. Converted to time, this reduction is equal to 5.1 minutes (22 minutes to 16.9 minutes).

Table A- 2: Mode Choice Model Example – New Mode

Mode	Travel Time (min)	Travel Cost ($)	Utility equation	Utility value	Demand
Auto	20	$2.00	B1*time + B2*cost	-1.40	74
Transit	45	$1.00	B1*time + B2*cost	-2.45	26
Auto	20	$2.00	B1*time + B2*cost	-1.40	57
Transit	30	$1.00	B1*time + B2*cost	-1.70	43

Thus, the total benefits derived from the new rail line for the 100 travellers between A and B are 510 minutes (100 travellers multiplied by the estimated travel time reduction of 5.1 equivalent logsum minutes).

Using the Rule of the Half (ROH) method the total benefits are 517 minutes, almost identical to the logsum estimate:

Benefits = 26*(45-30) + (43-26)*0.5*(45-30) = 517 person minutes

Whereby the new users, 43 less 26 trips, are assumed to accrue half of the benefits.

The minor difference stems from the demand curve 'linearity' assumption of the ROH method. **Figure A- 2** is an exaggerated version of the consumer surplus curve. The ROH method assumes the demand curve is linear. The logsum method approximates the true shape of the demand curve more accurately, specially if the demand curve is highly elastic[20].

20 The mathematical derivation is beyond the scope of this memo. In most cases, ROH is a reasonable approximation.

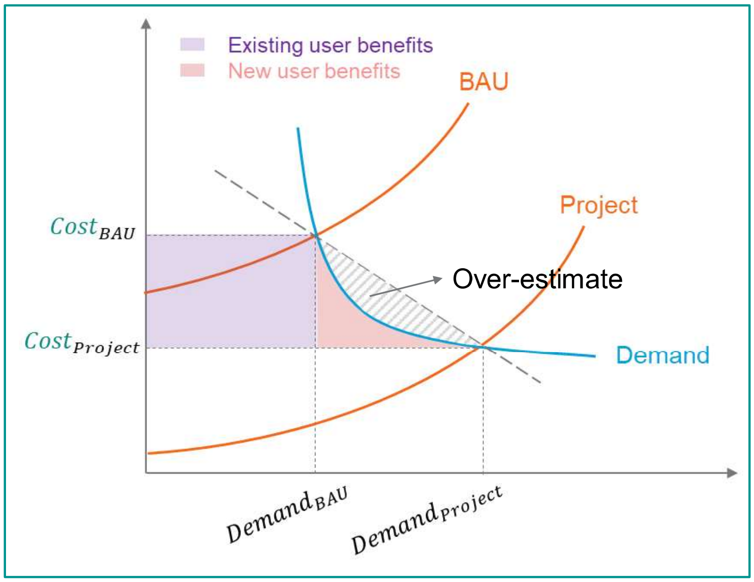


Figure A- 2: Exaggerated Consumer Surplus Curve

While the logsum method accounts for all the modes between an origin-destination pair, it does not account for distributional effects. Using the same hypothetical example presented above, if after building a new rail line the total trips from A to B increase to 105, the calculation presented so far would only account for the 'existing' 100 trip makers. To correct for this, a variation of the rule of the half is used where the additional five users who switched destinations are assumed to accrue half of the logsum benefit.

The difference here is that in the original ROH method, the linearity assumption applies to both existing travellers (ie the 100 trip makers in the example above) who switched modes and to new travellers who switched destinations. In the logsum method, the linearity assumption only applies to travellers who switched destinations[21]. For commuting trips (non-discretionary), distributional impacts as a result of new infrastructure or policy are smaller than travel mode impacts. In other words, people switch modes more readily than destinations. In the RTM, the logsum benefits are calculated using the equation shown below:

Equation A- 1: Logsum Benefits Equatio

$$Benefits\ (minutes) = \frac{1}{2}(Trips_{BAU} + Trips_{Project})(LS_{BAU} - LS_{Project})/\beta$$

This calculation is applied for each trip purpose and horizon year in the RTM. The term β is the in-vehicle-time coefficient for each trip purpose in the mode choice model.

While the ROH method is intuitively easier to understand, the logsum method, in addition to being more accurate, is surprisingly easy to calculate and offers several other advantages:

- **Flexibility**: In addition to travel time and cost, the logsum method can easily quantify other variables important to the decision maker and the economic analysis such as reliability and comfort so long as those variables are part of the mode choice model. While adding more variables for analysis is doable using the ROH approach, it is relatively effortless using the logsum method as all it requires is dividing the logsum, which is readily calculated for the mode

21 This is an artefact of having separate trip distribution and mode choice model. In a combined mode-destination choice framework the logsum can be calculated at the trip origin level.

choice model anyway, by the coefficient of travel time. An alternative specification of the mode choice utility shown previously that now includes reliability and comfort would be:

Utility = B1xtime + B2xcost + B3xreliability + B4xcomfort

- **Direct linkage with the mode choice model:** A main advantage of the logsum method is its direct linkage with the mode choice model. The logsum, naturally, is a direct outcome of the mode choice model and is linked to the choices people make to minimize the dis-utility of travel. Furthermore, the logsum method measures the impact of introducing new modes between pairs of origins and destinations more accurately. This applies in the case of the UBCx project where a new mode, a rail line, is introduced to the study area.

RTM Mode Choice Specification

Nine nested-logit mode choice models, one for each purpose, are coded in the RTM. **Figure A- 3** shows the mode choice model tree structure for the home-based work (HBW) trip purpose[22].

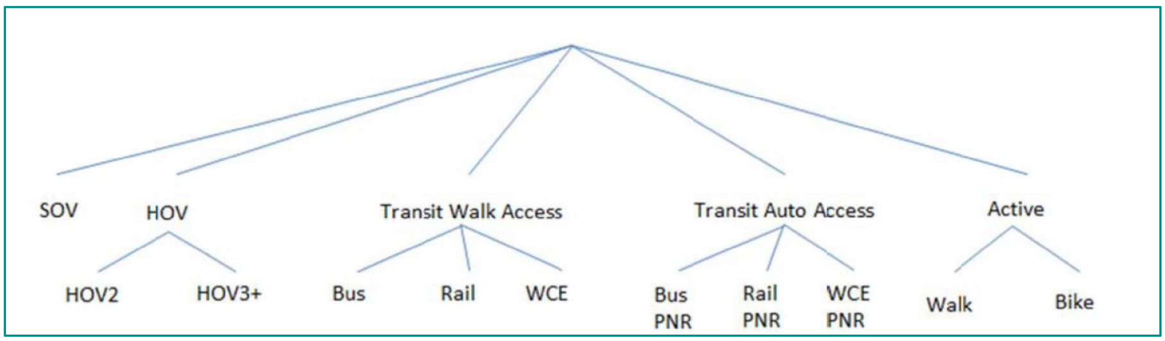


Figure A- 3: RTM Mode Choice Model Nesting Structure

In the RTM, bus, rail, and commuter rail (West Coast Express or WCE) are coded as three, distinct, hierarchical modes within the transit nest. A trip mode is considered rail if at least one leg of the trip is made by SkyTrain or SeaBus and commuter rail if at least one leg is made by WCE.

The utility for each mode in the mode choice model is of the form:

Equation A- 2: Utility Equation

$$V_i = ASC_i + \sum_{j}^{m} B_j \, . \, x_j$$

where i represents the mode and x_j is a set of explanatory variables such as time, cost or socio-economic characteristics. Income and auto ownership terms are included in several purposes. Thus, logsum matrices are calculated for each income and auto ownership segment. For example, in the home-based work purpose, nine logsum matrices are calculated (three income categories multiplied by three auto ownership categories).

22 Note, not all modes are available for all trip purposes due to a number of factors, including availability of the mode (West Coast Express only operates during the peak hours) and the availability of data to estimate the models.

The ASC term, or alternative specific constant, represents the average preference of travellers for one mode over the other that are not directly measured in the model. For example, in the home-based work trip purpose the alternative specific constant for the bus mode is -0.16 while the rail ASC is 1.6. In other words, a traveller prefers rail over bus, all other measurable attributes (time, cost, etc..) being equal. The ASC represents attributes, such as reliability and comfort which are not directly measured in the current mode choice formulation. Therefore, care needs to be taken to avoid double counting certain benefit accounts, such as reliability, for 'new users' (i.e. people who switch modes) since the logsum measure accounts for some of that effect in the ASC term.

Splitting Auto and Transit Benefits

Previous business cases typically split the travel time and cost benefits between the auto and transit modes. This calculation is straightforward using the ROH method but less intuitive for the logsum measure. The equation below shows how to calculate the transit component of the user benefits. The auto component is simply the difference between the total user benefits and the calculated transit benefits.

Equation A- 3: Transit Benefits Equation

$$Transit\ Benefits = \frac{e^{U_{Transit,Project}} - e^{U_{Transit,BAU}}}{e^{LS_{Project}} - e^{LS_{BAU}}} \times Benefits\ (minutes)$$

Where:

$U_{Transit,Project}$ is the transit utility of the project scenario

$U_{Transit,BAU}$ is the transit utility for the business as usual scenario

$LS_{Project}$ is the logsum of the project scenario

LS_{BAU} is the logsum of the business as usual scenario

ΔLS is the change in the total logsum between scenarios, and

$Benefits\ (minutes)$ are the total benefits calculated in **Equation 2-2**

Total logsum benefits are calculated for every origin-destination TAZ pair for each trip purpose. Since the mode choice models are specified at the daily level, all the benefits generated using the logsum method represent the average fall weekday benefits of a project for a given horizon year. **Figure A- 4** is a map showing a hypothetical example of daily minutes of user benefits using the logsum method for the Surrey Langley SkyTrain project in 2035. As expected, most the benefits cluster around the SkyTrain extension to Langley. A notable amount of benefits also accrues at locations that attract many trips such as the University of British Columbia, Simon Fraser University, and Sea Island (YVR Airport). A handful of traffic zones accrue negative benefits, however these are negligible (0.05% of the benefits total). Usually this occurs due to localized effects, such as re-routing or more crowding on transit at that location.

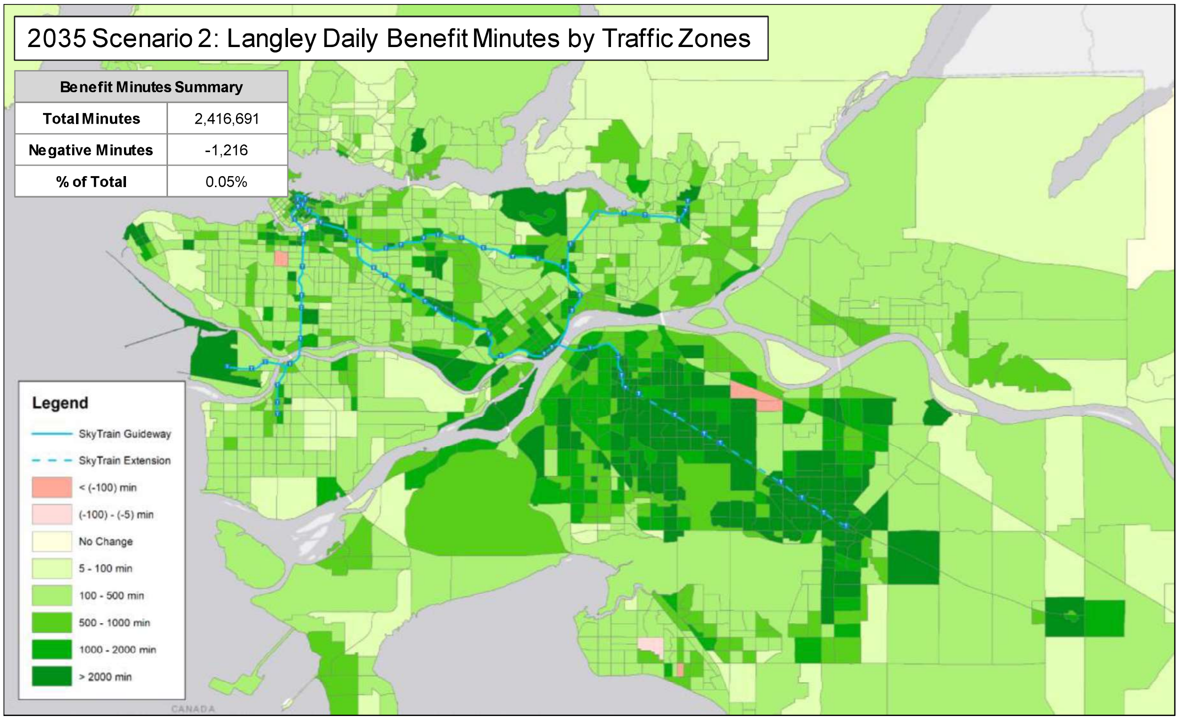


Figure A- 4: Example Daily Benefits by Traffic Analysis Zone (TAZ) in Minutes

Contact

Basse Clement, PEng, MASc
bclement@mcelhanney.com
Ali Darwiche, PEng
adarwiche@mcelhanney.com

McElhanney

CANADA BEST MANAGED COMPANIES