# EXPANDING THE MULTIPLE ACCOUNTS EVALUATION METHODOLOGY TO BETTER ASSESS RAPID TRANSIT TECHNOLOGIES: THE UBC LINE CASE STUDY

by

IONA TO

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# Abstract

Conducting a comprehensive evaluation of large-scale projects and programs such as a rapid transit development project is no small feat. The success of such programs can be influenced by a multitude of factors, such as existing local government policies, regional development trends, and the economic health of local communities. In turn, the implementation of such projects can have a wide range of environmental, social, and economic effects. Furthermore, these effects can change over time. The Multiple Accounts Evaluation (MAE) framework, which was first developed by the Provincial Government of BC, allows these influential factors and effects to be systematically evaluated quantitatively and qualitatively. The purpose is to present different perspectives of a given project and its alternatives, and help inform public policy debates.

Past studies that have applied the MAE approach to rapid transit projects, however, have excluded many of the more-difficult-to-measure, yet essential indirect and non-market factors. This study, therefore, sets out to develop a more comprehensive MAE framework to better assess the environmental, social, and economic effects of rapid transit technologies. Through an extensive review of the relevant literature, this study identifies the appropriate indicators to add to the MAE structure and develops techniques to measure them. In addition, this study explores this newly expanded framework in a real-life situation by applying it to two of the rapid transit technologies being proposed for the UBC Line in Metro Vancouver.

The findings of this study illustrate that some indirect and nonmarket effects such as accessibility and susceptibility to crime cannot be easily quantified. Nonetheless, there is a variety of qualitative indicators that can be used in place of quantitative metrics. Secondly, this study shows that data gaps do currently exist, and therefore at the present time some of the new indicators cannot be measured to the level of precision required for planning purposes. There are, however, steps that can be taken to address these gaps, such as conducting more field surveys and requiring better record keeping of resources consumed by a project.

In addition, there are several areas that require further study and actions that could be taken to conduct a more accurate MAE and improve the decision-making process. It is also argued that the MAE approach could be used more consistently in the future within the Province of BC and perhaps across Canada. In doing so, our natural and financial resources would be used more efficiently and sustainably, and unintended negative consequences of such large-scale projects would be minimized.

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# 1. Introduction

## 1.1 Research Problem and Focus of Research

There have been gaps identified in the Multiple Accounts Evaluation (MAE) framework, a tool used to determine the various effects of large-scale projects. The primary purpose of this study is to develop a more comprehensive MAE structure to better assess the environmental, social, and economic effects of rapid transit technologies. The hope is that this framework can be used by TransLink (Metro Vancouver's regional transit authority) and other transit planning agencies for future projects. With the MAE methodology expanded, the study also explores it in a real life situation by applying it to two of the technologies considered for the UBC Line in Metro Vancouver – an at-grade light rail transit (LRT) line and an underground SkyTrain line. The intent of the case study is to illustrate the evaluation techniques that could be used to measure the new set of criteria that have been added to the framework. The case study also identifies key pieces of data required for the pilot evaluation, sources of this data, as well as information gaps. In the process of developing the new MAE structure, the study also provides a critique of past MAEs that have been undertaken for major transportation projects within Metro Vancouver.

## 1.2 Background

The Multiple Accounts Evaluation (MAE) methodology is a tool first developed by the Province of British Columbia (BC) in the 1990s to help inform public policy. By dividing a major project/program and its effects into separate accounts, the framework allows the effects of the project/program to be measured quantitatively and qualitatively. Each account is intended to provide a different perspective so that Crown corporations can pursue a new project/program with a clearer understanding of its implications. The analysts who collect the data and conduct the evaluations do not use a pre-determined formal weighting scheme. Instead, it is up to the decision-makers to decide the relative importance of each account.

In 1999, an approach following the MAE methodology was used in the Vancouver Broadway Corridor (the Corridor) technical study (entitled *Beyond the B-Line*). The study was commissioned by the City of Vancouver, TransLink, and Rapid Transit Project 2000, and the purpose was to look at several different rapid transit alternatives for the Corridor from Commercial Dr. to the University of British Columbia (UBC) (see Figure 1-1). According to UMA et al. (1999), the consultants who conducted the study,

> "The [Broadway] Corridor features local retail and commercial buildings, single family and multi-family dwellings, recreational facilities such as the University Golf Club, and major regional destinations such as UBC and the Vancouver General Hospital. Broadway is also the main street of [Metro] Vancouver's second largest business district. Accordingly, a wide variety of users must be served, whether they are travelling locally or making long journeys from other parts of the City and Region." (p.2).

In recent years, the demand for transit along this Corridor (which includes W. 10th Ave, between Alma St. and UBC) has also significantly increased, especially by university students since the introduction of the U-Pass in 2003, and this demand often exceeds the current system's capacity.

Progress on the project, however, has largely been on hold for the last nine years. Although TransLink and the City of Vancouver supported rapid transit for the Corridor, other rapid transit projects such as the Canada and Evergreen Lines have been given higher priority. Now, TransLink is preparing to conduct a full MAE study to take another detailed look at different rapid transit technologies for the Corridor, and to account for the many new initiatives (e.g., the introduction of the U-Pass in 2003 at UBC and 2004 at SFU, the Canada Line opening in mid-late 2009, the anticipated Evergreen Line in 2013, the Vancouver streetcar demonstration project, and the proposed UBC below grade transit hub) that have developed since 1999 and will likely affect the Corridor and its linkage to the regional transit system. The project is now called the UBC Line and the expected in-service date is 2020 (Provincial Government of BC, 2008).

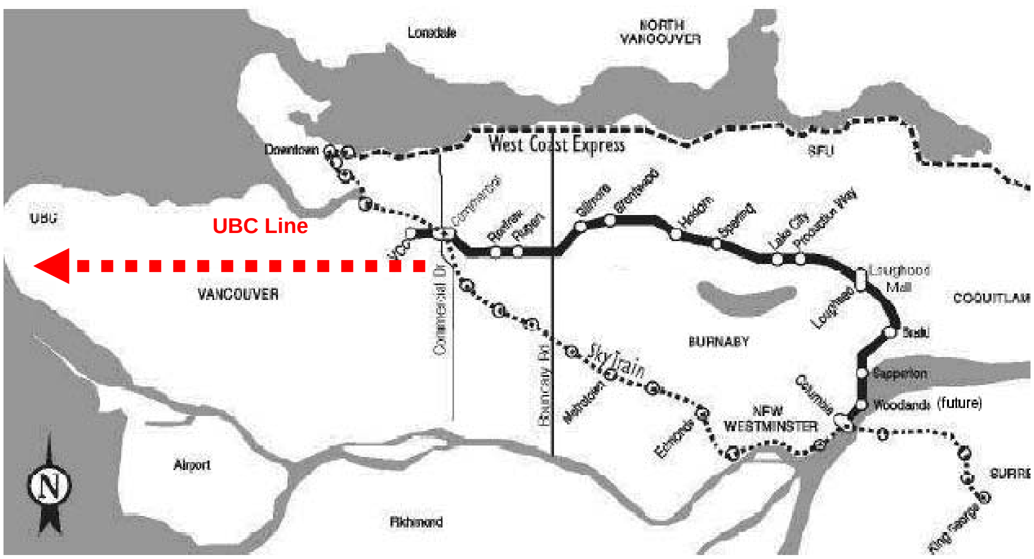


**Figure 1-1: The UBC Line currently being planned.** Source: UMA et al. (1999).

In the 1999 study, the analysis included the following accounts: financial; customer service; system operation; urban development; and environmental and community. Although this may appear to be a comprehensive list of accounts, many direct and indirect, as well as non-market, evaluation indicators were left out of the study. As pointed out by the present author in an earlier report (2008), the 1999 study did not include an economic development account, nor did it consider such environmental and social effects as air pollution from the operation of construction equipment and the contribution to community cohesion. The result was a less comprehensive evaluation.

This scoping issue, however, does not appear to be isolated to the Broadway/UBC Line study. At least two other rapid transit MAE studies – the Canada Line and Evergreen Line studies - have fallen short of including all the indirect and non-market essential costs and benefits (To, 2008).

As our populations continue to expand, local governments and transportation authorities will be required to make decisions that can meet multiple objectives. As such, the need to include all significant direct and indirect, market and nonmarket indicators in project evaluations will persist. As Litman (2009b) has stated,

> "Just as consumers need accurate and comprehensive information when making personal travel decisions, communities need accurate and comprehensive information on all significant impacts when making transport policy and planning decisions…Transportation policy and planning decisions affect virtually every aspect of life[, and] such decisions often involve tradeoffs between conflicting objectives. For example, strategies to increase vehicle travel speeds can increase crash risk and degrade walking conditions. Some emission reduction strategies increase vehicle costs or reduce total motor vehicle travel. Expanding parking supply increases building costs and taxes." (p.1-2).

Therefore, this study is of particular importance and the results will likely help local governments and transportation authorities in their future work.

The remainder of this report is organized into five chapters. Chapter 2 summarizes the literature that was reviewed and has helped inform the development of the expanded MAE framework. Chapter 3 describes the new criteria and indicators that have been added to the MAE methodology and highlights those that have been incorporated into the UBC Line case study. Chapter 4 describes in detail the evaluation techniques used and the results of the UBC Line study. The relative advantages of the LRT option are highlighted, especially with regards to the social and environmental effects such as the positive contribution to the pedestrian and bicycle environment, and the less intensive use of natural resources. The substantially lower capital cost is also emphasized. The relative advantages of the SkyTrain option are also described, including the ability to attract higher ridership due to the time savings achieved by the system, the lower operating cost, and the fact that there would be less disruption to the community during construction. As well, specific data gaps and challenges, such as the lack of information on linked ridership and the total vehicle kilometres traveled along the Corridor, are discussed. Chapter 5 describes in more detail the value of including the new criteria identified by this study and steps that can be taken to address data gaps, such as using trip diaries or the smart card system to compile linked ridership data. It also describes some of the areas that require further study and actions necessary to conduct a more accurate MAE and to improve the decision-making process. These include the use of critical values and discount factors; emphasis is also placed on the importance of public engagement and post-evaluations. Finally, Chapter 6 concludes the report by describing how the MAE approach could be applied more consistently in the future within the Province of BC and perhaps Canada. Appendix A provides a summary of the literature reviewed, Appendix B describes some of the evaluation methodologies in more detail, and Appendix C describes the sensitivity analysis included in the case study.

It is important to note that numerous simplifying assumptions have been made in the UBC Line case study. The cost estimates and other numerical values have been made with "orders of magnitude" precision only. More reliable data and further refinement of the analysis and development of the design of the technology options would be required before the information would be deemed to be robust enough for planning purposes. Furthermore, there is considerable uncertainty involved in forecasting events into the future. Therefore, the predicted benefits and costs may not be realized to the extent described in this study or at all. Additionally, the UBC Line case study assumes that the vision, goals, and objectives have already been identified for the project. In the actual UBC Line project, however, sufficient time would need to be spent on this task before the analysis can begin. The vision, goals and objectives will also have an impact on the development of the evaluation framework. Similarly, the actual design of the SkyTrain and LRT systems have yet to be determined. Hence it should be kept in mind there are alternative design options to what has been proposed in this study and the ultimate design chosen will have an effect on the evaluation outcomes. Lastly, due to resource and time constraints, only the new criteria and indicators and a subset of the criteria identified in previous MAE studies have been included in the UBC Line pilot evaluation.

# 2. Literature Review

To identify appropriate evaluation indicators for rapid transit projects, an extensive review of the relevant literature was conducted, the results of which are summarized in this chapter. The information is organized into several different subsections that illustrate the breadth of literature that has been examined and considered.

## 2.1 Conventional Economic Evaluation Methods

Economic evaluation methods, which measure the value of a program, policy, or project, are an integral part of project planning and management (Litman, 2006). They enable other aspects of the planning process such as collecting and disseminating information, consulting with the public, negotiating between stakeholders, and decision-making to occur more effectively and productively (*Ibid*). Economic evaluations consider market resources (e.g., those typically found in a conventional market) as well as non-market goods (e.g., environmental and social impacts such as water and air pollution). They can be done from the perspective of different individuals, groups, regions, jurisdictions, and even generations of populations. They can also have two general types of objectives: 1) efficiency, which aims to maximize the total social welfare and to reduce travel external costs; and 2) basic mobility and equity, which strives to distribute benefits and costs fairly (*Ibid*). Of course, sometimes efficiency and equity objectives can overlap since benefits to marginalized populations also often benefit the whole of society.

Typical economic evaluation methods include cost-effectiveness studies and benefit-cost analyses. The former method measures the cost of reaching a specific objective, such as building a bridge or increasing bus frequency during off-peak hours. The benefits or outputs remain constant, so there is only one variable - the cost of inputs (*Ibid*). Benefit-cost analysis, on the other hand, compares the total incremental benefits with total incremental costs. Therefore, there can be multiple objectives or benefits accruing from different project options. A value is placed on each incremental benefit and cost, and these are added together and compared; all the effects are expressed in monetary terms (*Ibid*).

For a large capital- and resource-intensive project such as the UBC Line, there are many objectives to achieve and many effects that cannot be expressed in dollar terms or quantitatively. Thus a benefit-cost analysis or a cost-effectiveness study would not be adequate. Multiple accounts evaluation or MAE, on the other hand, allows for many objectives and qualitative effects to be measured. It is therefore the selected framework for this study.

## 2.2 Multiple Accounts Evaluation

To fully understand the power and purpose of the MAE approach, it is imperative to examine the 1993 Crown Corporations Secretariat report, *Multiple Account Evaluation Guidelines*. The focus of these guidelines is on major plans and projects undertaken by Crown corporations. Due to the significant implications these projects can have on society, economy, and the environment, the report emphasizes the importance of Crown corporations pursuing projects with a clear understanding of the effects the projects can have. The MAE framework is meant to help Crown corporations systematically identify and evaluate the relative merits of alternative plans and projects, and to contribute to a well informed decision-making process. The underlying principles of the guidelines are as follows:

1. The evaluation process must be part of an integrated planning framework that explicitly recognizes the broader goals (both societal and corporate) of the project, and the spectrum of interests and activities of other Crown corporations and government agencies. Project plans should be developed in a collaborative process that involves provincial and regional community planning, high level system and strategic planning, policy/project/program planning, and design and engineering planning.
2. At the outset of the planning process, sufficient time needs to be spent on identifying the problem the project is supposed to address.
3. Several evaluation accounts should be implemented to clearly identify the advantages and disadvantages of different project alternatives.
4. The uncertainties and risks of a project should be identified to determine: a) the potential significance they may have on society and the Crown corporations involved; and b) the performance of the alternatives when unexpected changes occur. This can be accomplished by performing sensitivity analysis, which examines the effects of changing the value of a variable, or scenario analysis, which involves changing the values of a set of variables. Risks are typically associated with economic, demographic and market factors, technological performance and duration, environmental impacts, and political and regulatory constraints.

The guidelines also recommend the following list of accounts to be included in an MAE:

- Financial performance;
- Customer service;
- Environment;
- Economic development; and
- Social.

However, the report notes that, “Not all accounts are relevant in all evaluations. In some cases, there may be no significant implications or matters of concern under a number of accounts.” (p.9).

The financial account documents the revenue and expenditure implications of the alternatives from the perspective of the Crown corporation and the provincial government as a whole. The effects a project may have on other Crown corporations and provincial ministries are also carefully considered. The main summary measure of financial performance is the discounted sum of the annual net revenues (i.e., the net present value or NPV) gained by the corporation and the rest of the provincial government. The guidelines also make the following recommendations:

- Apply a discount rate of 8% real when conducting a base case analysis, and perform sensitivity analysis at 6% and 10% real to determine how different discount rates would affect the cost of the project.

- Consider the project's affect on the total revenues and expenditures of the whole system (e.g., TransLink's entire transit system). These implications should also be determined for the long term.
- Only consider the "first order" effects (i.e., direct revenues and expenditures collected or incurred by the corporation or other levels of government from the project). The financial effects resulting from a change in total employment, population or sales in the economy should not be included due to the complexity of the whole economy.
- Determine the remaining or salvage value of the project to identify any differences in the asset mix at the end of the planning period.
- Conduct sensitivity analysis, as a number of key assumptions will be made in the financial calculations.

The customer service account focuses on the net benefit or value that alternatives bring to users. These benefits can be described in either monetary or non-monetary terms. If it is the latter, a critical value (the amount that a non-monetized advantage or disadvantage would have to be in order to offset the identified financial impacts) can be used to analyze their relative importance. If the alternatives affect customer groups differently, it is recommended these implications be recorded from the perspective of each individual group.

Meanwhile, the environmental account serves to document the major biophysical and natural resource impacts of the alternatives. This account is not intended to replace a full environmental impact assessment. Rather, it is meant to highlight the key local, regional, and provincial ecological impacts. Again, the impacts can be expressed in either monetary or non-monetary terms. In the latter case, as with the customer service account, it is recommended that a critical value be included.

The economic development account analyzes the nature, magnitude and significance of the income and employment effects (in monetary or non-monetary terms) of the alternatives. The focus should be on the net benefits, as opposed to gross impacts, that new employment or economic activity creates. Thus emphasis should be given to the alternatives' ability to increase sustainable income opportunities.

Lastly, the social account documents the alternatives' effects on the social fabric and values of the affected communities or groups, including aboriginal peoples. Like the environmental account, the goal is not to conduct a full social impact assessment. It is only meant to record the major community or distributional effects the alternatives may have. It could include variables such as community population stability, quality of life, and equity considerations. Due to the complexity of converting social benefits and costs into dollar values, it is recommended that effects be measured in non-monetary terms.

Once all of these effects are recorded, the results are presented in a summary matrix, and the sources of risk and risk management strategies are then identified. According to the guidelines, the inclusion of critical values in the matrix can also help decision-makers settle trade-offs in an informed manner.

## 2.3 General Effects of Rapid Transit

Now that an explanation of the MAE structure has been provided, the following section describes some of the general effects rapid transit systems can have. It is important to note this is not an exhaustive list of factors to be considered in a transit project assessment. They are simply the effects emphasized in the literature and can be generalized to all types of rapid (and sometimes even conventional) transit. In the following section, the focus is on the specific advantages and disadvantages of different technologies. Regardless of whether these impacts are general or specific to a form of rapid transit, however, all of them should be taken into account when evaluating rapid transit projects and should be reflected in MAE frameworks.

### 2.3.1 Taking a System-Wide Approach

Before proceeding further though, the work of Richmond (2001) is worth noting here. He advocates that when assessing the effects of a transportation project, a system-wide approach should be taken. After reviewing all of the new US light rail projects in operation as of April 1997 (which includes projects in Baltimore, Buffalo, Dallas, Denver, Los Angeles, Pittsburgh, Portland, Sacramento, San Diego, San Jose and St. Louis), he concludes that "new transit projects are traditionally assessed in isolation from the total transit systems in which they are set." (p.150). For example, he notes that while many studies have examined the issue of developing complementary bus systems to serve light rail lines, they have usually neglected to view bus and rail systems as an integrated network. Consequently, they have often left out the cost of feeder bus operations in the financial calculations. In his opinion, many governments are also often too quick to favour rail transit; the claimed benefits of rail such as providing relief to congestion and access to jobs for the poor, appealing to 'choice-riders' (higher income commuters who could drive to work if they wished), and enhancing natural environments may be exaggerated. He found that rail systems are not necessarily more cost-effective to run than bus systems and in fact their performance can be less than stellar if they are not evaluated thoroughly with a system-wide approach during the planning process. He raises issues that some rail systems have had, such as severe capital cost over-runs, lower than expected ridership levels (this is further explored below), lower operating speeds, and an overestimation of the quality of bus feeder service. To remedy this, Richmond (2001) recommends evaluating new transit projects from a system-wide perspective. This means including the following elements in an assessment whenever possible:

- Examine the change in ridership level of the entire transit system as opposed of just the proposed system.
- Assess changes to linked ridership, which counts the number of complete journeys made regardless of how many transfers are made en route, instead of unlinked ridership, which counts the total boardings on all vehicles. Linked data makes it possible to compare the total number of transit journeys made before and after a new transit project is implemented, while unlinked data may inflate the actual number of transit trips made after a new project is in place. (Note: In reality linked ridership can typically only be estimated, not physically counted, unless a smart card system allows tracking of linked trips).

- Compare the cost per unit output of the proposed system with the cost-effectiveness of the current system.
- Consider the modification to other transit modes as a result of the proposed system being implemented.
- Consider the number of transfers users need to make on the new system from their place of origin to their final destination.

While some of these elements may be more difficult to incorporate into an MAE framework, doing so would make the evaluation more holistic and complete.

### 2.3.2 Attracting Higher Transit Ridership

Let us now further examine rapid transit's ability to increase ridership, which is one of the most common objectives of building a higher quality transit line. As mentioned earlier, it is often believed that constructing a rapid transit line will make public transit more attractive. Yet some researchers have found the actual patronage on some capital-intensive projects has been well below the initial forecasted numbers. Studies by Pickrell (1992), Kain (1990), Babalik-Sutcliffe (2002), and Flyvberg et al. (2005) have seemed to indicate that many earlier transit projects have experienced this problem. For example, Flyvberg et al.'s 2005 study, which examines 27 rail projects constructed between 1969 and 1998, concludes that 9 out of 10 projects had inflated ridership estimates and that approximately 72% of the projects had overestimated their patronage by more than two thirds (the average overestimation for all of the studies was 105.6%).[1] The authors believe that these overestimates were largely due to trip distribution values being adapted to meet policies aimed at increasing rail traffic and "deliberately slanted forecasts" were made to favour rail. Furthermore, they found that the projections did not become more accurate over the 30-year time period. Thus they recommend that "the most effective means for improving forecasting accuracy is…more realistic assumptions and systematic use of empirically based assessment of uncertainty and risk" (p.138).

At the same time, however, Litman (2009a) notes that Pickrell's usage of first year ridership data is an inadequate indicator of the long-term effectiveness of a transit system. It typically takes much longer for a new transit line to "mature" as commuters fully adapt to the change in the transportation network. Litman (*Ibid*) also reports that recent ridership estimates have often underestimated public transit patronage, especially for rail transit systems over a longer period of time. According to Litman, once a rail line is built, ridership has often grown beyond original expectations. For example, as of 2000, the Dallas light rail system, DART, had exceeded ridership expectations by approximately 10% (*Ibid*). Similarly, the Denver light rail line, which opened in 2000, experienced 67% more ridership in 2001 than initially projected (*Ibid*). The Minneapolis Hiawatha/Central LRT and the Portland MAX LRT also exceeded the 2005 ridership forecasts. In the case of Minneapolis, they were able to reach their 2020 target by 2005. Burgess and Rood (2009) have also documented many other rapid transit systems, such as LA Metro's Orange Line, that have surpassed their original ridership projections. It can therefore be concluded that there is no consensus on the accuracy of ridership projections. It would appear that lessons have been learned from earlier projects, and that more recent ridership calculations have been more robust and ridership is now often exceeding initial estimates. However, further

[1] These values exclude the two statistical outliers in the study.

refinement of the calculation methods is still required as significant gaps between projected and actual achieved ridership levels still remain. This implies that when conducting MAE studies, careful attention should placed on refining the calculation methods and assumptions used.

### 2.3.3 Increasing Land Values

It has also been argued that transit improvements can make an area more economically, culturally, and socially accessible (e.g., by reducing transportation costs, increasing commercial activity and attracting amenity services, and relieving congestion problems). This, in turn, is reflected through increases in development and land value, which tend to be localized around transit stations (Parsons Brinkerhoff, 2001) (see Figure 2-2). Some have argued that properties within very close proximity to a rail system could be subject to noise, pollution, and loss of privacy. However, both Debrezion et al. (2007) and Smith and Gihring (2002), who have conducted extensive analysis and review of the relevant literature, have shown that property values do rise with increased access to transit. Debrezion et al., (2007), for example, found that residential properties within a quarter mile of a station are approximately 4.2% more expensive than the average residence, and commercial properties are about 16.4% more expensive than the average commercial property. Edge (2003) also claims that in North America residential and commercial properties within immediate transport corridors can have land value premiums of 5-10% and 10-30%, respectively. Al-Mosaind et al. (1993) found similar results in Portland, OR, where proximity to transit stations added an average of 10.6% premium to residential properties. A report by Parsons Brinkerhoff (2001) has also noted that the effect on development and property values appear to be less dependent on the type of rapid transit technology as it is on the reliability, frequency, and speed of service.


**Figure 2-1: Example of development attracted around Portland's streetcar system.**
Source: Alliance for Regional Transit (2009).

These increases in development and land value can also occur before a transit line is actually built and continue after a system comes into operation. If plans for a new transit system are well known and perceived to be definite, property values can begin to rise well before the system is built (McDonald and Osuji, 1995). For example, the Chicago Midway Line was eventually opened in 1993, but the anticipation of the system was reflected in the increase in property values starting in the late 1980s, and perhaps as early as 1987 (*Ibid*). In addition, Cervero (2004) has found that land value premiums and development intensity can increase with proactive planning, network development, and system maturation, as was the case for the Santa Clara light rail system.

It is also worth noting that the negative impacts of living within close proximity to a transit station may not apply to multi-family buildings as much as to single-family homes. As Gruen and Jeans (1993) explain,

> "The construction and layout of apartment buildings typically better withstand the noise and intrusion on privacy that a station can create. Apartment dwellers are relatively more transient, and thus maybe less troubled by these disamenities. Because renters are less sensitive than homeowners to factors influencing long-term values, property values for multifamily rental projects maybe less adversely affected by station disamenity effects. Apartment dwellers also place a higher premium on transit access. [Therefore,] apartment projects located closer to train stations obtain higher rents and maintain higher occupancy rates than comparable apartments less conveniently located." (p.25).

Gruen and Jeans therefore recommend encouraging higher density, multi-family buildings in areas close to transit stations (this is discussed in further detail below). In addition, to further mitigate the proximity problem, municipalities can consider adopting Proximity Guidelines, which ensure station designs are integrated with the needs of the surrounding communities (Earth Tech Canada, 2007).

Returning to the topic of land value premiums, many planners and economists, including Nobel laureate William Vickrey, have suggested utilizing these premiums to fund transit system development and operating costs (Doherty, n.d. and J. J. Smith and Gihring, 2006). This approach has been adopted or at least considered by many places. The UK, for example, utilizes value capture funding, also known as a 'betterment tax', to fund public infrastructure costs. Currently, they are considering using value capture methods to fund the UK (*Ibid*) Crossrail project in London. Los Angeles also has a 'Special Assessment District' system where a differentiated property tax rate is applied to an area that has received infrastructure improvements. For example, when a new rail line is built, properties within 400-800 m of a station are expected to contribute to the operational cost of the rail system (*Ibid*). Similarly, Portland, Oregon, has Local Improvement Districts, where certain capital improvements are made within a defined area and site rent is collected within this area to help fund these improvements. In France, employers are expected to contribute to the operational costs of public transit through a special tax ('versement du transport'). This funding scheme has provided stable financial support for the public transit system and has enabled 10 light rail systems to be built since 1985 (*Ibid*). The Central Puget Sound Regional Transit Authority also utilizes several types of taxes (e.g., employer tax, a special motor vehicle excise tax, and a sales and use tax) to fund its operations.

### 2.3.4 Attracting Transit-Oriented Development

Related to the ability to increase development and land value is the ability of rapid transit systems (bus and rail) to encourage high-density transit-oriented development (TOD). This, in turn, increases transit ridership (Currie, 2005) and reduces urban sprawl. The Portland streetcar and the Ottawa Transitway are exemplary examples. Condon et al. (2008) found that as of 2008, since the construction of the streetcar network began in 1997, the realized density potential (measured using the standard floor area ratio) within one block of the streetcar line was 90% higher than in blocks farther away.

The Ottawa Transitway (Figure 2-3), a BRT line, has also attracted over $1 billion of transit-oriented development at stations (Currie, 2005). However, in order to be successful in encouraging high-density development, Currie (2005) notes that BRT systems need to implement the following measures:

- Exclude or carefully manage park-and-ride facilities, which would discourage TOD (this is also true for rail systems);
- Implement car-restraint policies throughout the community (also true for rail systems);
- Provide extra levels of leadership and intervention than rail-based TOD, as evidence suggests that implementing bus-based TOD is more challenging;
- Implement strategies to ensure there is a high-quality and direct pedestrian access to the bus station (this can be difficult as a major bus station could have high volumes of bus movement, posing danger to pedestrians);
- Minimize noise and air pollution from buses as much as possible; and
- Ensure speed and frequency is comparable to a rail system (this would require measures such as transit-priority signals and exclusive rights-of-way).

**Figure 2-2: Articulated bus used for bus rapid transit in Ottawa.** Source: OC Transpo (2009).

Therefore, in MAE studies that include BRT systems, the inclusion or lack of these measures in the system design would factor into the evaluation results.

### 2.3.5 Increasing Net Development within a Region

It is also important to note that although local development may increase, from a region-wide perspective, the net development gain resulting from a transit improvement may actually be zero. A study conducted by Knight and Trygg (1977) conclude that transit systems do not increase overall development in a region, and other researchers such as Handy (2005) have supported this claim. A report by Cervero and Seskin (1995) also states that "urban rail transit investments rarely 'create' new growth, but more typically redistribute growth that would have taken place without the investment" (p. 3). Thus transit is a more useful tool in influencing where in the region growth occurs rather than increasing overall growth (but only if the right conditions exist, a point that is further explored in Section 2.5).

### 2.3.6 Other General Effects

Continuing on with the discussion of general transit effects, Litman's work (2008a, 2008b, and 2009b) has been reviewed to identify additional impact categories that should be considered but have not been incorporated into any of the rapid transit evaluations reviewed (see Table 2-1). For the purpose of this study, these effects are organized according to the evaluation account into which they fit. A more detailed description of each impact category can be found in Table 3-1 and Section 3.2.

**Table 2-1: Impact categories identified by Litman and typically excluded in transportation evaluation studies**

| Account | Impact |
|---|---|
| **Financial** | Roadway costs (e.g., road repair costs) |
| **Customer Service** | Security<br>Reduced vehicle traffic congestion |
| **Economic** | Reduced parking facility costs |
| **Social** | Community cohesion |
| **Environmental** | Construction impacts on environment<br>External costs of resource consumption |

Litman (personal communication, February 3, 2009) emphasizes, in particular, that customer service effects such as travel time savings play an especially significant role in the success of a transit line. This claim is supported by arguments made earlier by Richmond (2001), Babalik-Sutcliffe (2002), Hass-Klaus and Crampton (1998), and Ben-Akiva and Morikawa (2002).

## 2.4 Comparison of Different Rapid Transit Technologies

Now, we move on to the specific differences between various forms of rapid transit. As most of the literature compares rail to bus rapid transit, it is also the main focus of this section. There are, nevertheless, also differences between various types of rail transit and one of these is further discussed in this section. These differences can include speed of service, spacing of stations (thus the distribution of development), alignment, infrastructure requirements, and vehicle types, all of which can also be used to compare bus and rail transit. Therefore, all these effects should be measured and included as criteria within the MAE framework. There are, of course, other differences between the various rapid transit modes (e.g., vehicle capacity); the ones discussed here are mainly the differences from the user's perspective.

To start off the comparison between bus and rail systems, Ben-Akiva and Morikawa's (2002) study, which compares the attractiveness of bus and rail systems, was reviewed. Their research shows that people's mode choices are influenced by level-of-service factors such as: reliability; comfort; security from crime; availability (e.g., locational availability); and safety from collisions. Yet these factors are often neglected in evaluation studies as they are difficult to quantify. This section will examine each of these factors, as well as others, in more detail.

### Reliability

In terms of reliability, rail service can have a completely exclusive or semi-exclusive right-of-way and therefore avoid competing with other modes. An express bus service that runs on an exclusive right-of-way can also provide a similar level of reliability. In addition, bus systems have the ability to use alternate routes when regular routes are blocked (*Ibid*). Bus systems are also less prone to system-wide delays, whereas the failure of a single train can block an entire line of rail service (*Ibid*).

### Safety

Yet when it comes to safety, Ben-Akiva and Morikawa (2002) believe users may perceive rail systems to be safer than buses due to their mechanical guidance, mechanized train control systems and avoidance of other modes.

### Comfort, Security from Crime, and Availability

The conclusions, however, on comfort (which includes both the inside of transit vehicles and in waiting areas), security from crime, and availability seem to be less clear. Rail systems offer smoother rides and seats can be more spacious, and the waiting areas of rail systems are typically more comfortable than bus stops. Rail stations are also usually busier than bus stops, which are widely dispersed and therefore less secure, and rail service is typically more frequent (although the frequency of BRT could be made comparable to rail transit). Furthermore, the accessibility of a bus driver relative to a train operator is more of a perceived rather than an actual safety benefit, as trains and their stations are often monitored by video surveillance. On the other hand, there are often more standees on trains, and bus stops are usually within walking distance of a larger portion of the population.

### Service Expansion

In addition, a study completed by Bruun (2005) reveals that it is more cost-effective to provide additional capacity to BRT systems with less than 1,600 spaces-per-hour than to rail systems with comparable capacities. The opposite is true for lines with more than 2,000 spaces-per-hour, as the BRT headway becomes so low that traffic signal priority becomes ineffective. This creates service inefficiencies and increases unit costs. Brunn (2005) has also found that the marginal cost of providing off-peak service is lower for LRT than for BRT.

### Travel Speed

Adding to that, Deen and Pratt (1991) have indicated that BRT systems that offer non-stop services and have their own rights-of-way can travel faster than rail as they can reach non-stop speeds of 64-80 km/hr. Indeed, within Vancouver itself, the #99 Commercial Drive/UBC express B-Line (the B-Line) was operating non-stop services along the Corridor for a period of time, during which trip times were significantly reduced.

With that being said, Ben-Akiva and Morikawa (2002) concluded that a bus rapid transit system with a high quality of service and an exclusive right-of-way could potentially be as attractive to riders as rail systems. However, as Litman (2009a) has pointed out, incorporating these features could increase the costs closer to that of rail systems.

## 2.5 External Factors that Make Rapid Transit Systems Successful

While a new rapid transit line has the potential to attract development into transit station areas and corridors, transit alone cannot bring about substantial positive land use changes (Handy, 2005). Therefore, in this section, a review of the major external factors that make rapid transit system successful is provided.

Through an extensive review of the available literature and through first-hand experience, Knight and Trygg (1977) have found the following four conditions necessary to bring about considerable land use changes and successful transit systems:

1. Local government policies encouraging development;
2. Regional development trends;
3. Availability of developable land; and
4. Physical constraints of the site.

Many studies conducted since have also supported these claims (e.g., Babalik-Sutcliffe, 2002 and Cervero, 2004). It is therefore concluded that they should also be considered in transit evaluation studies. In this section, their influence on transit performance and transit-oriented development is explored in further detail.

First of all, Babalik-Sutcliffe's (2002) research has found that local government policies such as "the allowance of liberal floor area ratios, density bonuses at designated locations, changes in zoning plans, marketing of air rights, sale of excess land parcels, and urban renewal - all implemented at strategic locations near a transit station or along the corridor - may have a very significant impact on development" (p.237). These policies not only encourage higher density development, they can also control to an extent where and what type of development will occur. Cervero (2004) further adds that providing assistance in land assembly such as purchasing land, facilitating deals, and coordinating different entities would also attract developers into an area. So too would financial incentives such as tax increment financing. This is a tool often used to reduce the costs of development to the private sector by dedicating tax increments (the additional property tax revenue that will be generated once the redevelopment has taken place) within a certain defined area to finance debt issued to pay for the project. Therefore, when conducting a rapid transit evaluation, analysts should determine to whether these policies are already in place or could be introduced in the near future.

Secondly, regional development factors such as population growth and economic and social health can affect the demand for transit (Babalik-Sutcliffe, 2002 and Knight and Trygg, 1977). The presence of a transit line may help to direct and/or accelerate growth to specific areas, but it alone cannot create new regional growth or increase transit patronage (Knight and Trygg, 1977). For example, Babalik-Sutcliffe (2002) claims that low-income and very high income communities would not be suitable for urban rail. In low-income communities, the rail system fares may be cost-prohibitive, while in very high income areas high-density developments are generally not viewed as desirable. Litman (2009a), however, states that rail systems can improve access to employment for low-income individuals and numerous systems today are used by low- and middle-income households. Many middle- and higher-income travelers are also willing to pay additional taxes to fund rail transit improvements, but are less willing to provide such funding for bus projects (*Ibid*). Furthermore, once a rail system is built more citizens are often willing to support bus expansion to further improve network coverage. Thus while attention should be given to the economic and social health of neighbourhoods in which transit stations and corridors are situated, each community should be evaluated on a case by case basis. The residents of one affluent neighbourhood may not support a rail system, but another equally wealthy community may see the advantages of having a rail station in their neighbourhood.

Thirdly, the availability of developable land and the physical characteristics of the areas to be served by the new transit line should be considered. Without suitable land for development, land use changes simply cannot occur. Physical attributes such as the following may also encourage or discourage further development: regional role of the area; presence of compatible land uses or intense development; number of property owners around station areas with whom negotiations would have to occur to acquire land for redevelopment; and proximity of the area to existing and new developments. An example of the last condition is the Portland MAX light rail extension to the airport. The construction of this line was made possible by the investment of a private developer who was interested in building a new employment centre at the airport (Anonymous, n.d.). The assumption was that the new MAX line would help attract employers and employees to the new centre. It is therefore recommended that evaluation studies consider the effect of such synergies.

In addition, although rapid transit projects could reduce traffic congestion and improve air quality, such investments alone do not necessarily generate these results (Babalik-Sutcliffe, 2002). However, if policies on car restrictions (e.g., reduction in parking availability) accompany these projects, then perhaps changes would occur. In evaluation studies, consideration should therefore be given to whether such practices are or could be incorporated into the design of a new rapid transit project.

## 2.6 Rapid Transit for Broadway Corridor

To help set the context for the UBC Line case study, the following section describes the projects that have explored rapid transit options for the Broadway Corridor. A review of this literature provides valuable insights into: a) the indicators and alternatives that have been considered for the Corridor in the past; b) the effects that have been left out in these previous studies; and c) the techniques that could be utilized to measure some of the old and new criteria. These key elements and gaps are also summarized in Table 2.3.

### 2.6.1 MAE of Rapid Transit Options for Greater (Metro) Vancouver

In 1994-95, BC Transit (who, at the time, was responsible for BC's entire transit system) and the Crown Corporations Secretariat conducted an MAE to compare several rapid transit options for three corridors in the Vancouver region (see Figure 2-1). These corridors were: 1) Broadway-Lougheed (of which the first phase is now the Millennium Line, and the second phase is the proposed UBC Line); 2) Coquitlam-New Westminster; and 3) Richmond-Vancouver. In this project, as was the case for all of the MAE studies described in this chapter, time was spent at the beginning of the project on defining the problem statement, vision, and objectives. As noted in the *MAE Guidelines*, this is a key initial step. The technologies considered were Rapid Bus (or bus rapid transit), conventional LRT, and automated LRT such as SkyTrain. Five accounts were included – financial, customer service, environmental, urban development, and system operations. A number of key criteria were incorporated into these accounts, such as: contribution to regional land use goals; promotion of compact development; ridership; lifecycle cost per boarding; and net social costs (e.g., travel time savings). However, other factors were left out, such as: the time it takes to transfer between modes; station accessibility; susceptibility to crime; other factors that impact travel time savings, such as the comfort of the vehicles; and air and water quality impacts from construction.

At the end of the study, for the Broadway-Lougheed Corridor, it was concluded that an at-grade LRT system would have a low lifecycle cost per boarding, a low net social cost, and a high ridership. It would, however, make a low to medium contribution to the regional land use goals. A SkyTrain-type technology would have the highest lifecycle cost per boarding of any of the alternatives considered, a higher net social cost than LRT by 60%, and the highest ridership. It would also make a medium to high contribution to regional land use goals. In the end, the MAE did not recommend a specific technology but did recognize the relative cost-effectiveness of a Broadway-Lougheed rapid transit system and its potential to increase transit ridership.

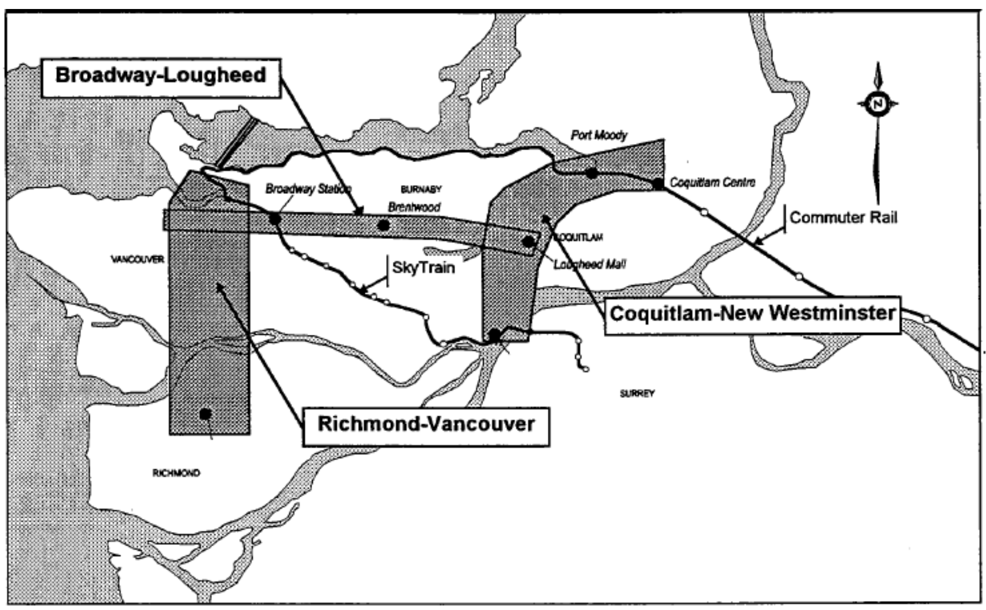


**Figure 2-3: Rapid transit corridors considered for Metro Vancouver in the 1994-95 MAE study.**
Source: Crown Corporations Secretariat (1995).

### 2.6.2 Beyond the B-Line

A few years after the above study was completed, one of the most important reports informing the present study was conducted, during which six different rapid transit options were examined for the Broadway Corridor. This study attempted to answer the following questions: what combination of rapid transit technologies should be considered and how do these alternatives compare to each other? The target year was set at 2021 and the alternatives (which would operate between Commercial Dr. and UBC) included Rapid Bus, LRT, and four different combinations of an underground SkyTrain line with Rapid Bus. As mentioned in Chapter 1, there were five accounts, and each account included a set of quantitative and qualitative criteria. The study's final recommendation was that the SkyTrain line be extended to Granville St. and that a Rapid Bus line be established between Granville St. and UBC.

A review of the study's report, however, reveals that a number of key factors were missing, including:

- Operating revenues;
- Land-based impacts, such as geotechnical and construction-related issues, bio-environmental impacts, and cultural/heritage impacts;
- Air quality impacts from construction; and
- Salvage value.

In addition, the study completely excluded the economic account and the analysis only looked at the short term ridership effects, ignoring the fact that ridership will take a number of years to mature. In many instances, the report also did not provide many details on the assumptions that were made in the assessments. Moreover, the study did not include a sensitivity analysis. Consequently, no efforts were made to identify project risks or risk management strategies. It is for these reasons, along with the fact that TransLink is now preparing to conduct a full MAE for the Broadway Corridor, that this study has chosen the UBC Line for the pilot evaluation.

## 2.7 Other Rapid Transit Case Studies and Evaluation Methodologies

In the process of developing a comprehensive framework to assess rapid transit systems, other studies that have conducted similar types of analyses were also reviewed. The key elements drawn from each of these studies and reports, as well as the identified gaps within these studies, are outlined in Table 2-3.

### 2.7.1 Local Case Studies

The first three transit systems examined are the Millennium Line, Canada Line, and Evergreen Line, all of which are local examples and were also subject to MAE studies. As mentioned in the previous section, an MAE conducted in 1994-95 looked at SkyTrain, LRT, and BRT options for the Broadway-Lougheed, Richmond-Vancouver (now known as the Canada Line) and Coquitlam-New Westminster corridors (now known as the Evergreen Line). At the time, the study concluded that a Broadway-Lougheed rapid transit system would be cost-effective and would likely increase transit ridership. It also acknowledged that the implementation of rapid transit in the Coquitlam-New Westminster corridor would enable regional growth management objectives to be met. Meanwhile, although the Richmond-Vancouver line had the highest ridership, it also had the highest capital cost. Furthermore, the Richmond-Vancouver corridor had little potential to densify growth. Rapid transit was therefore not considered justified along this corridor.

Soon after this study was completed, another study was commissioned by the Rapid Transit Office to take another look at rapid transit options for the Broadway-Lougheed Corridor. A decision was then made to build phase I of the Corridor (the Millennium Line) and that it would be a SkyTrain Line. In response to this decision, in 1999, Greer, the principal author of the 1994-95 Metro Vancouver rapid transit MAE study, wrote a memorandum to the Crown Corporations Secretariat arguing that the estimates used by the Rapid Transit Office for LRT and SkyTrain were flawed when the Office was making the case for the Millennium Line to be built. According to Greer, the RTP studies inflated the cost of a storage and maintenance facility for LRT. Moreover, including only the Millennium Line portion of the Broadway-Lougheed Corridor in the study likely created a more favourable situation for SkyTrain. The use of two different consultants to assess SkyTrain and LRT also led to different assumptions and evaluation methods being used. In addition, the capacity advantage of SkyTrain was likely exaggerated (the higher end of the range of SkyTrain capacity was compared to the lower end of the range of LRT capacity). There was also no ridership or demand analysis conducted, which meant the reduction in air pollution and traffic congestion could not be reasonably estimated. Furthermore, Greer argued that there was an overstated support for SkyTrain over LRT, as surveys presented the LRT option in an unattractive light, and an underestimation of the construction time for the SkyTrain option. In summary, this memorandum illustrates how evaluation studies can be utilized to produce biased results that favour a particular type of technology. It also emphasizes the importance of remaining objective when conducting evaluations.

Then, in 2001 another MAE study was conducted to determine the implications and relative merits of implementing rapid transit along the Richmond/Airport-Vancouver Corridor in 2010 versus 2021. In other words, the study was used to help decide when rapid transit should be established along this corridor. Although the study examined two general types of rapid transit systems - shared right-of-way and exclusive right-of-way - the actual alignment and technology to be used was decided in a subsequent phase. In the study, the following accounts were included: financial; transportation user benefits; environmental; urban development; economic development; and social and community. Incorporated into these accounts were essential criteria such as: bus capital and operating cost savings; time and vehicle operating cost savings; reduced collision risk; vehicle emission reductions; geological and bio-environmental impacts; cultural/heritage impacts; contaminated lands impacts; land value effects; and contribution to regional land use and transportation goals. The report also specified some of the assumptions made and evaluation methodologies utilized. In addition, a sensitivity analysis was performed by varying the trip making and travel preferences, service levels, financial assumptions, and design parameters. The study, however, did the not consider the following factors: duration of construction; air and water quality impacts from construction; road run-off reduced during service life; and effects on users' physical activity. Nor did it include the impact of increased construction costs in the sensitivity analysis, and no efforts were spent on identifying risks or risk management strategies.

Moving onward, in 2004 another MAE was also completed for the Coquitlam-New Westminster Corridor by IBI Group. The objective of this study was to evaluate a number of alignment and technology options that could provide intermediate capacity transit service from the Millennium

Line to the communities in the Northeast Sector. Five accounts were included: transportation; urban development; environmental; social; and ease of implementation/extendibility. The report details the assumptions made and the evaluation methods used in the assessments. It also includes a number of criteria not found in the 1999 Broadway study, such as: impacts to water, green space, and natural habitats; visual effects; community severance; station accessibility; potential for phasing; technology risk; and contamination risk. Sensitivity analysis was also performed by varying certain assumptions that would affect ridership and criteria within the transportation account. However, it neglected to consider factors such as: air and water quality impacts from construction; resource impacts from construction; effects on pedestrian and bicycle environment; and susceptibility to crime. Furthermore, the sensitivity analysis did not consider all key parameters and no risk management strategies were devised.

### 2.7.2 US and International Case Studies

#### US Examples

In addition to the three local examples, other relevant case studies and research include those from the United States (US) and United Kingdom (UK), as well as Australia. In particular, the US and UK have extensive experience in developing and applying transportation evaluation methods. For example, the US Federal Transit Administration (FTA) has been using alternatives analysis for advancing local fixed guideway transit projects for over 25 years (Federal Transit Administration, n.d.). Moreover, under the *US Transportation Code,* projects seeking New Starts funding actually need to be based on the results of alternatives analysis (*Ibid*). The purpose of an alternatives analysis is to explore and investigate an array of potential transit options. Similar to the MAE process, at the outset of a study, time is spent defining the problem that the project is trying to solve and establishing a vision and set of objectives that will guide project evaluation. Then, the alternatives to address the purpose and needs are developed and evaluated. Throughout this time, comprehensive and continual public involvement is maintained (CTA, n.d.). There may be multiple screening stages to narrow down the alternatives, and the results of each screening stage are presented at public meetings (*Ibid*). At the end of the analysis, a Locally Preferred Alternative is determined (*Ibid*).

One such development that has applied alternatives analysis is the Burnside/Couch project in Portland, OR, which is focused on determining the best future use of West Burnside and Northwest Couch St. (DKS Associates, 2006). In the analysis, ten transportation and urban design concepts that considered traffic and transit operations, livability, and economic development potential were developed; each alternative was also evaluated against a set of transportation and urban design criteria. Table 2-2 provides a list of the components of each transportation criterion and a brief description of the urban design measures. For each criterion, a five-point ordinal evaluation scale that ranged from poor to good was used. Although this project looks at more than just rapid transit options for Burnside/Couch Streets, it does highlight some important urban design criteria that are often left out of transportation evaluation studies. Therefore, it has been included in this literature review.

**Table 2-2: Components and description of the transportation and urban design criteria used in the Portland Burnside/Couch project**

| Transportation Criterion | Components |
|---|---|
| **Auto safety** | • Assessment of potential conflict points at signalized and unsignalized intersections, and the potential for increased or reduced vehicle volumes along the corridor |
| **Pedestrian safety** | • Number of signalized pedestrian crossings<br>• Implementation of signalized crossings at existing high motor vehicle/pedestrian collisions<br>• Crossing distance for pedestrians<br>• Sidewalk widths along West Burnside |
| **Vehicle operations** | • Travel times<br>• Travel speeds<br>• Level-of-service at intersections<br>• Volume-to-capacity ratios<br>• The number of vehicles potentially using alternative routes within the surrounding roadway network and ability of these alternative routes to accommodate this traffic |
| **Vehicle access/circulation** | • Ability to make left turns<br>• Potential for out-of-direction circulation for property access |
| **Transit operations** | • Provision of transit operations to connect to future light rail and current streetcar network |
| **Bicycle mobility** | • Ability to provide safe bicycle crossings at West Burnside |
| **Diversion acceptability** | • Number of vehicles that could be diverted to another parallel surrounding roadway<br>• Available capacity on the surrounding roadway network |
| **Urban Design Criterion** | **Description** |
| **Urban Scale** | • Pedestrian scale (relative size of objects, elements and spaces compared to the dimension and proportions of the human body)<br>• Objects and elements of scale (how objects and elements share and define the public right-of-way and organize the space between buildings and the roadway)<br>• Balancing space (amount of area assigned to pedestrians vs. vehicles) |
| **Urban Form** | • Impact of the dimensions and interconnections between streets and public or private space at the ground plane on the horizontal form of the area<br>• Impact of the edges and vertical planes formed by buildings, bridges and other objects on views, and scale and shape of urban spaces |
| **Urban identity** | • Presence of cultural and historical references, such as architecture, public art, and public and private activities |
| **Linkages** | • Presence of paths, urban spaces and views that connect objects, features and destinations within neighbourhoods, districts, and the city to reinforce and enhance the pedestrian system. |
| **Sustainability** | • The ability to integrate programs and practices that conserve energy, reduce waste and eliminate redundant processes |

In addition to this analysis, four potential streetcar alignments were evaluated against the following criteria: impact to capacity; impact to traffic operations; impact on parking; ability to cross I-405; and bicycle/pedestrian effects. In this evaluation a three-point ordinal scale (good, medium, poor) was used. Adding to this, a cost-benefit analysis was also conducted to evaluate three alternative plans for street improvements, with and without the streetcar.

Multiple stakeholders were also involved in the development of the key assumptions and in the review of the evaluation results. The end product was a set of recommendations that would enhance the transportation and urban livability along West Burnside and Northwest Couch Streets.

Overall, this study has included many valuable urban design criteria and has demonstrated how multiple stakeholders can be engaged during a project evaluation. However, it has neglected to consider the financial and economic implications of the alternatives. Other factors that could have been considered include effects on local businesses and on users' level of physical activity. It would have also benefited from a sensitivity analysis.

Another US example is the Columbia Pike Transit Initiative in Arlington County, VA, which looked at different transit alternatives to better serve the rapid growth of the Columbia Pike (Washington Metropolitan Area Transit Authority, 2005). Similar to the Broadway Corridor, Columbia Pike is a mixed-use employment, commercial, and residential area that includes major regional attractions including the Pentagon, Pentagon City, and the Skyline complex. As such, a higher-quality transit system was needed. In the evaluation, criteria similar to what has been previously described in this chapter were used. These included issues of access and mobility, community and economic development, safety, reliability and comfort, regional connections, consistency with community goals, and costs; they also included both quantitative and qualitative measurements. In contrast to the Burnside/Couch project, however, the quantitative results were not converted into an ordinal scale. Instead they were presented in their original forms. Qualitative measurements were presented in using the high-medium-low or yes-no ordinal scales. As in the case of the Portland study, multiple stakeholders were also involved in the development of the project goals (which were later used to define the evaluation criteria). In addition, updates were provided to the public during the analysis phase and prior to the study's conclusions being finalized to share findings and recommendations. This study therefore provides another example how of multi-stakeholder and public engagement can be incorporated into the project evaluation process. The final recommendation was that a small-scale streetcar project be pursued.

The main elements that are found to be missing in this study include: consideration of the environmental implications of the project; a sensitivity analysis; and consideration of the operating revenue that would be generated by each option.

**UK Example**

In the UK, the New Approach to Appraisal (NATA) is the methodology used to evaluate transportation investments. Initiated in 1998, it is a multi-criteria analysis tool that builds on cost-benefit analysis and environmental assessment techniques. On the *Transport Analysis Guidance* website, WebTAG, the UK Department for Transport (DfT) outlines a total of 15 steps for the study process. It begins with the development of project objectives and ends with the monitoring of a project's environmental impacts (UK Department for Transport, 2009). The primary outputs of the approach are: 1) an appraisal summary table (AST) that documents the environmental, economic, and social effects of the option(s); 2) an assessment of each option's achievement of regional and local objectives; 3) an analysis of the extent to which the problems identified earlier in the study would be solved by the option(s); and 4) supporting analyses covering issues of distribution and equity, affordability and financial sustainability, and practicality and public acceptability. Similar to the results matrix developed for an MAE, an AST does not dictate a particular way to estimate the value for money for a given option. It does, however, provide an overview of the effects in each category so that decision-makers have a more comprehensible and transparent basis on which to reach a resolution. The five main categories of effects included in the AST are environment, safety, economy, accessibility, and integration. Criteria introduced by the NATA framework and not included in the other literature reviewed are: user charge (i.e., the fares that users have to pay); personal physical fitness; travel time variability; and practicality and public acceptability.

Although weighting factors are not provided by the AST, the UK DfT guidelines do discuss different types of decision techniques that can help identify preferred options from the results of a multi-criteria analysis. These techniques include the use of ordinal or cardinal scoring, weighting factors, and multi-attribute utility models, all of which would aggregate the results into a single value. Hence, the main difference between the NATA and MAE methodologies is that the latter analyzes the benefits and costs of alternative projects for society as a whole and does not attempt to aggregate all the net benefits into a single bottom line measure. In contrast, a multi-criteria analysis will not necessarily consider the effects on society as a whole; rather, the effects are determined by the stakeholders and politicians (Shaffer, personal communication, February 12, 2009). In addition, in the NATA methodology, not all affected parties' preferences are taken into account in the weighting schemes applied to the various indicators. Instead, the weighting is dependent on the decision-making rules that have been established (*Ibid*).

### Australian Example

Continuing further abroad, Campbell and Brown (2005) from the University of Queensland in Brisbane, Australia have developed a spreadsheet-based multiple account framework that is better suited for projects funded through the private sector or via public-private partnerships. It focuses on analyzing a project from different perspectives and includes the following analysis sections:

- Project analysis: this includes the costs and benefits of the project in monetary terms, based on market prices.
- Shareholder analysis: this looks at the benefits and costs to the private shareholder.
- Efficiency analysis: this takes into account social costs and benefits that can be measured in monetary terms.

- Reference group analysis: this divides the net benefits calculated in the efficiency analysis into the net benefits accruing to different stakeholder groups within society (e.g., taxpayers, customers, etc.).

Unlike the MAE framework, the results (net benefits) are only expressed in monetary terms. Therefore, some of the effects that cannot be monetized are likely missed. Yet, this method does emphasize the importance of addressing market failures in a systematic way and the importance of analyzing projects from multiple perspectives.

Table 2-3 provides a summary of the key elements that were drawn from the above case studies, as well as some the gaps that were found in the studies. The 1999 *Beyond the B-Line* report is also included in this table.

**Table 2-3: Key elements drawn from and gaps identified in case studies and evaluation methodologies**

| Report | Key Elements of Importance | Key Gaps |
|---|---|---|
| **Multiple Account Evaluation of Rapid Transit Options for Greater (Metro) Vancouver**<br>(Crown Corporations Secretariat, 1995) | • Shows how the MAE framework has been applied in the past to evaluate three local corridors' potential for rapid transit.<br>• Key indicators include: contribution to regional land use goals and promotion of compact development; ridership, lifecycle cost per boarding; and net social costs. These indicators, along with the evaluation methodologies used to measure them, could be incorporated into other rapid transit MAEs. | • Economic account is missing.<br>• Other effects not considered include: the time it takes to transfer between modes; station accessibility; susceptibility to crime; other factors that impact travel time savings, such as the comfort of the vehicles; and air and water quality impacts from construction. |
| **Beyond the B-Line: Broadway/Lougheed Rapid Transit Line (Phase II – Commercial Drive West)** (UMA, Lloyd Lindley and Davidson Yuen Simpson Architects, 1999). | • Report shows: how the MAE framework has been applied specifically to the Broadway Corridor; what factors and alternatives have been considered in the past; how some of the effects can be measured quantitatively or qualitatively; and what variables should be considered when evaluating rapid transit options for the Corridor.<br>• Report provides the initial MAE framework on which this study is based. | • Economic account is missing.<br>• Other effects not considered include: operating revenues; land-based effects, such as bio-environmental impacts; air quality impacts from construction; and salvage value.<br>• Did not provide enough details on the assumptions made in the assessments.<br>• Sensitivity analysis not included and no efforts made on identifying risks or risk management strategies. |
| **Review of Rapid Transit Project Claims**<br>(Greer, 1999) | • Illustrates how evaluation studies can be utilized to produce biased results that favour a particular type of technology, and shows the importance of remaining objective when conducting evaluations. | • N/A |

| Report | Key Elements of Importance | Key Gaps |
|---|---|---|
| **Canada Line Multiple Account Evaluation**<br><br>(IBI Group, 2001) | • Includes essential indicators such as: bus capital and operating cost savings; salvage value; time and vehicle operating cost savings; reduced collision risk; vehicle emission reductions; geological and bio-environmental impacts; cultural/heritage impacts; contaminated lands impacts; land value effects; and contribution to regional land use and transportation goals. These indicators, along with the assumptions and evaluation methods utilized to measure them, could be incorporated into other rapid transit MAEs.<br>• Shows key parameters to examine in a sensitivity analysis. | • Effects not considered include: duration of construction; air and water quality impacts from construction; road run-off reduced during service life; and effects on users' level of physical activity.<br>• Impact of increased construction costs not included in sensitivity analysis.<br>• No efforts spent on identifying risks or risk management strategies. |
| **Evergreen Line Multiple Account Evaluation**<br><br>(IBI Group, 2004) | • Includes important indicators such as: impacts to water, green space, and natural habitats; visual effects; community severance; station accessibility; potential for phasing, technology risk; and contamination risk. These indicators, along with the assumptions and evaluation methods utilized to measure them, could be incorporated into other rapid transit MAEs.<br>• Demonstrates how a sensitivity analysis can be conducted for ridership and for indicators within the transportation account. | • Effects not considered include: air and water quality impacts from construction; resource impacts from construction; effects on pedestrian and bicycle environment; and susceptibility to crime.<br>• Sensitivity analysis did not consider all key parameters.<br>• No efforts spent on identifying risks or risk management strategies. |
| **Portland Burnside/Couch Alternatives Analysis**<br><br>(DKS Associates, 2006) | • Demonstrates how any evaluation result can be presented qualitatively using an ordinal scale.<br>• Unlike other studies reviewed in this chapter, it places more emphasis on urban design aspects and includes them as key evaluation criteria. This is an approach that could be taken by other rapid transit evaluations.<br>• Involvement of multiple stakeholders in the development of key assumptions and in the review of evaluation results could be an approach followed by other rapid transit studies. | • Did not include a financial or economic account.<br>• Did not include effects on local businesses or on users' level of physical activity.<br>• Did not include a sensitivity analysis. |

| Report | Key Elements of Importance | Key Gaps |
|---|---|---|
| **Columbia Pike Transit Alternatives Analysis**<br>(WMATA, 2005) | • Columbia Pike has similar characteristics as the Corridor. Therefore, the study is a great example of what evaluation criteria should be considered for such heavily used urban environments and how these criteria can be measured quantitatively and qualitatively.<br>• Involvement of multiple stakeholders in the development of project goals (which were later used to define the evaluation criteria) and throughout the project could be an approach followed by other rapid transit studies. | • Main elements missing: consideration of the environmental implications of the project; a sensitivity analysis; and consideration of the operating revenue that would be generated by each option. |
| **UK Transport Analysis Guide**<br>(UK DfT, 2009) | • Demonstrates another way of analyzing and presenting transportation evaluation results to decision-makers.<br>• Includes important indicators such as: user charge; personal physical fitness; travel time variability; and practicality and public acceptability. These indicators could be incorporated into rapid transit MAEs. | • N/A |
| **A Multiple Account Framework for Cost–Benefit Analysis**<br>(Campbell and Brown, 2005) | • Emphasizes the importance of addressing market failures in a systematic way and analyzing projects from multiple perspectives. | • N/A |

## 2.8 Relevant Plans and Policies

Relevant local, regional, provincial, and federal plans and policies should also be reviewed when developing an evaluation framework, as the goals and targets within these documents can serve as evaluation criteria. The relevant goals and objectives identified for the UBC Line case study include the following:

a) TransLink's goals contained in *Transport 2040* (2008c) to aggressively reduce greenhouse gas emissions from transportation and shift the majority of the trips taken in Metro Vancouver towards transit, walking, and cycling. The supporting initiatives described in the TransLink *2009-2018 Ten Year Plan* (2008a) are also relevant.

b) The *Provincial Transit Plan's* (2008) goals to: reduce provincial transportation greenhouse gas emissions by 4.7 million tonnes cumulatively by 2020; increase transit mode share in Metro

Vancouver from 5% to 17% by 2020; develop a $2.8 billion rapid transit line out to UBC by 2020; create healthier communities that are more desirable to live, work, and visit; and connect communities across Metro Vancouver.

c) Regional transportation and growth management objectives contained in Metro Vancouver's *Livable Region Strategic Plan* (1999) and the draft report, *Our Livable Region 2040*: *Metro Vancouver's Growth Strategy* (2008). Such objectives include: promoting TOD and focusing growth in Urban Centres and Frequent Transit Development Corridors; fostering the development of inclusive and supportive communities with access to a range of amenities and services; and connecting land and transportation decisions to reinforce a compact region, Urban Centres, and Frequent Transit Development Corridors.

d) City of Vancouver's goals including: a transit mode share target of 38% for Central Broadway as identified in the *Vancouver Transportation Plan* (1997); the greenhouse gas reduction targets established in the report, *The Climate-Friendly City: A Community Climate Change Action Plan for the City of Vancouver* (2005); and other related objectives such as allocating more road space to transit, designating space for cyclists, and improving pedestrian comfort and safety.

e) UBC's goals to: increase the use of transit, cycling, and walking; encourage the usage of clean-fuel transit vehicles; decrease single-occupancy vehicles; and develop an automobile-restrained transportation system. Also relevant are the transit-supportive initiatives identified in UBC's *Official Community Plan* (Metro Vancouver, 1997), *Comprehensive Community Plan* (UBC, 2000), *Main Campus Plan* (UBC, 1992), *Strategic Transportation Plan* (UBC, 2005), *University Boulevard Neighbourhood Plan* (UBC, 2003), and the draft *UBC Vancouver Public Realm Plan* (UBC Office of Architect, 2008).

## 2.9 Summary

Table A-1 in Appendix A provides a summary of the transportation benefits and costs that have been covered in this chapter, as well as a list of the relevant literature reviewed for each topic (presented in chronological order). The studies that have followed the MAE approach are marked with an asterisk to show which indicators are typically left out of rapid transit MAE studies. These key gaps are also summarized in Table 2-4 and described in further detail in Chapter 3.

**Table 2-4: Indicators typically left out of the MAE framework**

| Account | Indicators Typically Neglected in MAE Studies |
|---|---|
| **FINANCIAL** | • Cost of traffic services<br>• Consideration of land value-capture funding |
| **CUSTOMER SERVICE** | • Traffic congestion reduction benefits<br>• Impact of new transit projects on total system performance and affordability<br>• Presence of accessibility-enhancement features at stations<br>• Susceptibility to crime<br>• Equity effects<br>• Impact on personal physical fitness |

| Account | Indicators Typically Neglected in MAE Studies |
|---|---|
| **SOCIAL AND COMMUNITY** | • Consistency with all relevant plans and policies (including UBC in the case of the UBC Line)<br>• Ability to attract transit-oriented development<br>• Effect on community cohesion<br>• Effects such as emphasis of the human scale, overall attractiveness of public realm, and presence of cycling infrastructure<br>• Practicality and public acceptability |
| **ENVIRONMENT** | • Impacts of resource consumption for construction<br>• Emissions of air pollutants generated from construction |
| **SYSTEM OPERATION** | • Travel time variability |

# 3. The New MAE Framework

This chapter begins with an explanation of how the literature described in Chapter 2 has been applied in this study. It then describes the new criteria and indicators that have been added to the MAE framework and where necessary, explains the rationale for including them. The chapter ends by highlighting the criteria and indicators used in the UBC Line pilot evaluation to measure the effects of SkyTrain and light rail transit.

## 3.1 Development of the New MAE Framework

In the development of a new comprehensive MAE framework, this study has considered all of the literature cited in Chapter 2. The evaluation framework from the 1999 Broadway Corridor study is used as the initial starting point, and new criteria and indicators, including all of those listed in Table 2-4, have been added. The organization of the accounts has also been restructured so that the criteria, indicators, and accounts are better aligned. Recommendations from the *Multiple Account Evaluation Guidelines* have also been followed, with additions and modifications made where appropriate. In addition, the general effects of rapid transit systems and the more specific advantages and disadvantages of different technologies described in Sections 2.3 and 2.4 have been taken into consideration. Lastly, where possible, the recommendation made by Richmond (2001) to analyze the effects new transit projects have on total system performance has been included.

For the purpose of this project, the perspective is from the region of Metro Vancouver and the main objectives focus on efficiency. However, equity objectives are also embedded within some of the evaluation accounts. Examples include: station accessibility by all users; user charge; and the impact of the modified bus system on users. Additionally, the present study acknowledges that increases in land value around one corridor or area does not necessarily equal to a net gain in development on a regional level. Thus it does not use the transit systems' influence on land value directly as a criterion. Yet it is still recognized that some of this additional land value could be captured to finance the transit system. Therefore, the effect on land premiums is considered within the financial criterion, *ability to generate land-value capture funding*.

The external factors that can influence the success of a rapid transit system have also been incorporated into the framework. Furthermore, the plans and policies summarized in Section 2.8 have been reviewed to ensure the new MAE structure reflects the goals and objectives outlined in these policy documents and plans.

It should be noted that the framework has been developed with the UBC Line in mind. Therefore, the focus year for the evaluations is 2021, which for the purposes of this study will be the UBC Line's first full year of operation. However, this MAE structure could be modified and adapted for any rapid transit project.

## 3.2 Evaluation Accounts, Criteria, and Indicators of the New MAE Framework

The MAE framework is based on a hierarchical structure of accounts, criteria and indicators. Within the new comprehensive framework, there are a total of six evaluation accounts - financial, customer service, economic development, social and community, environmental, and system operation. Two of the criteria that are normally included in the urban development account – *consistency with city and regional goals and objectives* and *ability to generate positive land use changes and achieve the minimum density requirements to support the rapid transit technologies* - have been placed in the social and community account. This change in placement allows another similar criterion to be included in the same account - *consistency with UBC's plans and policies,* which is not entirely captured in the definition of 'urban development'

Figure 3-1 is a conceptual diagram of how the MAE structure is organized, and Table 3-1 provides a brief description of all the criteria and indicators (the latter of which is used to measure the effects of each criterion) included in this expanded MAE framework. To avoid complicating Figure 3-1, only the economic development account has been divided into its subcomponents. In reality, however, all of the accounts contain multiple criteria and indicators. Those that have been added to the MAE structure by this study are shown in italics in Table 3-1; they are also described in more detail within the text following the table. Only those shaded in grey are included in the UBC Line case study.

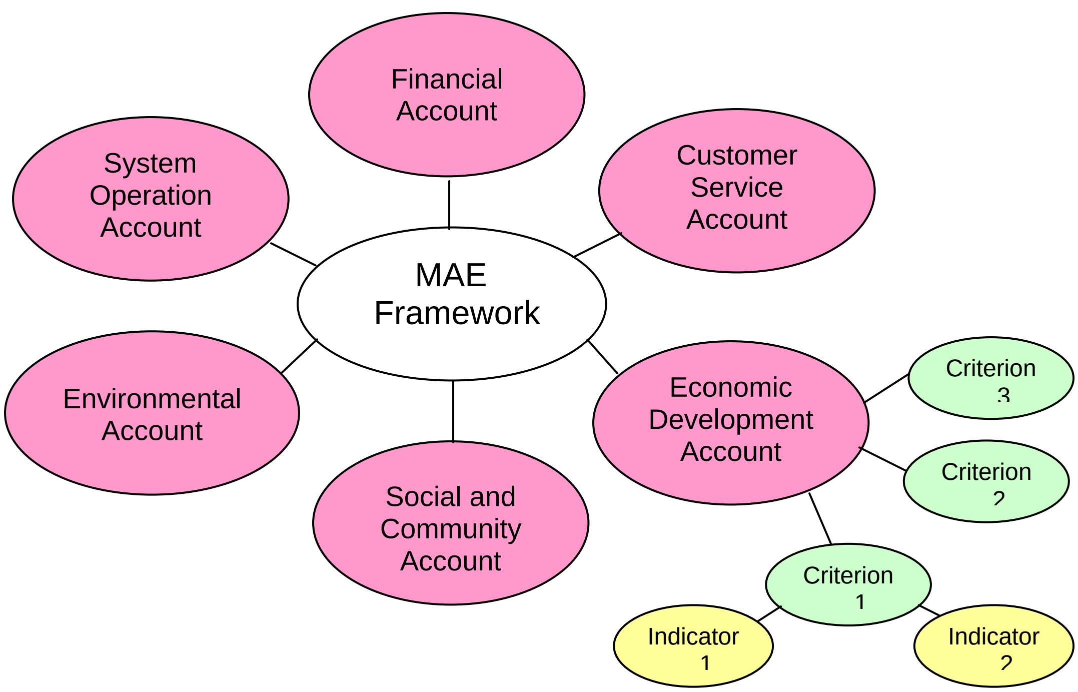


**Figure 3-1: Conceptual diagram of the new MAE framework**

It is important to keep in mind that this study has not conducted a full evaluation, as the focus is on the development of a new MAE framework rather than selecting a technology and design for the UBC Line. Therefore, as mentioned in the paragraph above, only the indicators shaded in grey in Table 3-1 are included in the UBC Line case study. These include all the new criteria and indicators this study has added to the MAE framework, as well as a subset of those included in previous MAE studies. The latter group of criteria has been selected based on the availability of data, the complexity of the measurements required, and the feasibility of generating reasonable estimates given the time and resource constraints of this study.

**Table 3-1: A summary of the accounts, criteria, and indicators of the new MAE framework**

| | Evaluation Criteria | Description of Criteria | Key Indicators (Data to Collect and Report On) |
|---|---|---|---|
| FINANCIAL | Capital cost ($2009) | The total cost to plan, construct and purchase rapid transit technology. This includes, but is not limited to, the cost of building new maintenance and policing facilities, landscaping, relocating utilities, geo-technical testing (to confirm the subsurface soil, bedrock and groundwater conditions), excavating and disposing excavated materials, and any required treatment of contaminated lands. | • Total capital cost<br>• Capital cost per passenger km<br>• Capital cost per new passenger (based on ridership levels in 2021) |
| | Operating cost in 2021 ($2009) | The direct operating and maintenance costs. | • Total annual operating cost<br>• Annual operating cost per service hour<br>• Annual operating cost per passenger<br>• Annual operating cost per new passenger relative to base case (i.e., status quo) |
| | Operating revenue in 2021 ($2009) | The revenue collected through the fare box and transit passes. | • Total gross annual operating revenue<br>• Gross annual operating revenue per passenger |
| | Bus capital and operating savings, and other transportation infrastructure savings in 2021 ($2009) | The savings achieved from redistributing some of the Broadway buses to other routes. | • Total bus capital savings<br>• Annual bus operating savings<br>• Annual road repair/rehabilitation cost savings (due to reduced road traffic) |
| | Remaining or salvage value ($2009) | The value of the proposed system and its vehicles at the end of its useful life. | • Cost estimate of the system and vehicles at the end of its useful life |
| | *Cost of traffic services ($2009)* | *The cost to provide policing, emergency response, law courts, street lighting, and parking enforcement.* | • *Annual cost of providing these services (broken down by category if possible)* |

| | Evaluation Criteria | Description of Criteria | Key Indicators (Data to Collect and Report On) |
|---|---|---|---|
| | *Ability to generate land value-capture revenue* | *The ability to attract development to the station areas and system corridor and to utilize land value-capture financing mechanisms to fund transit.* | • *Potential to generate land value-capture funding (given current regulations and the proposed system's propensity to attract development)* |
| | Benefits and costs of reduced parking | The annualized savings of not having to provide parking spaces and the reduction in parking fees collected. | • Annualized savings of not having to provide parking spaces ($2009)<br>• Annualized reduction in parking fees collected ($2009) |
| **CUSTOMER SERVICE** | Ridership (*linked ridership if possible)* | The ability of the proposed system to attract riders, as measured by the predicted annual ridership in year 2021 (the first full in-service year) and the annual ridership new to transit in year 2021 relative to the base case. | • Annual ridership in 2021<br>• Annual ridership new to transit in 2021 relative to the base case |
| | Connectivity | The ease of transfers between other transit modes and the proposed system. | • The time it takes to make transfers at various points in the system (includes walking time plus average headway/2), such as:<br>o Expo SkyTrain Line to UBC Line<br>o Millennium SkyTrain Line to UBC Line<br>o Canada Line to UBC Line<br>o Bus (at various locations) to UBC Line |
| | Travel time savings ($2009) | The reduced cost to consumers, as they spend less personal time on travel, and the reduced cost to businesses, as they spend less paying employees to travel. The reduction in travel time cost takes into account traveler comfort, which is affected by factors such as cleanliness, the heating and cooling ventilation system, lighting, vehicle and station design, etc. Travel time savings would also be accounted for in the ridership projections so the results cannot be combined together. | • Reduced cost to consumers<br>• Reduced cost to businesses |
| | Vehicle cost savings ($2009) | The reduced fixed costs for vehicle purchases or leases, insurance, registration and vehicle taxes, and reduced variable operating costs for such things as fuel, maintenance, and parking fees, etc. | • Reduced fixed costs<br>• Reduced variable operating costs |

| | Evaluation Criteria | Description of Criteria | Key Indicators (Data to Collect and Report On) |
|---|---|---|---|
| | Collision cost reductions ($2009) | The annualized savings that motorists gain by avoiding vehicle collisions due to a shift to public transit, walking, and/or cycling. | • Annualized savings that motorists gain by avoiding vehicle collisions |
| | *User charge* | *Fares paid by users* | • *Fare schedule* |
| | *Impact of modified bus system on users* | *The number of bus routes removed or modified, and the effects on local bus users* | • *Number of bus routes removed or modified and to what extent*<br>• *Effects of bus modifications on passengers who want to use buses to make short local trips* |
| | *Traffic congestion reduction benefits ($2009)* | *The external cost a vehicle imposes on other motorists.* | • *Net reduction in congestion cost relative to base case (considering the reduction of private vehicles and, if applicable, the increase of public transit vehicles operating in mixed traffic)* |
| | *Station accessibility* | *The ease with which the station can be accessed by all types of users.* | • *Presence of accessibility-enhancement features such as: level floor boarding, audio and visual signs, and pavement markings*<br>• Platform location in relation to the sidewalk |
| | *Susceptibility to crime* | *The effect of the proposed system design on users' sense of personal security* | • *Presence/lack of system design features that affect users' sense of personal security, such as: visibility of the stations in relation to surface traffic, presence/lack of video surveillance, and presence/ absence of a driver or operator inside the vehicle* |
| | *Effect on personal physical fitness* | *The proposed system's ability to promote users' physical activity.* | • *Ability to attract service amenities within a 500 m walking distance of the stations, which allows users to easily access these amenities by active modes of transportation* |

| | Evaluation Criteria | Description of Criteria | Key Indicators (Data to Collect and Report On) |
|---|---|---|---|
| | *Diversity of trip needs met* | *The ability of the proposed system to serve a diversity of trip needs.* | • *System performance for long trips (e.g., a point east of Commercial Dr. to UBC), as measured by comparing the time spent in transit vehicles with the time spent accessing the station platforms*<br>• *System performance for shorter local trips (e.g., Main St. to Macdonald St., and Main St. to Cambie St.), as measured by comparing the time spent in transit vehicles with the time spent accessing the station platforms* |
| ECONOMIC DEVELOPMENT | Effect on tax revenue collected | The effect on tax revenue collected and the effect on the regional GDP. | • Reduction in fuel taxes collected<br>• Potential property tax revenue gained<br>• Effect on regional GDP<br>• Effect on business tax revenue collected |
| | Impact of construction and operation on local businesses | The effect on businesses along the transit corridor during construction period. | • Estimated business losses along transit corridor during construction period<br>• Estimated business losses by business type |
| SOCIAL AND COMMUNITY | Consistency with City and Regional goals and objectives | This is measured by whether or not the proposed system supports Regional and City livability goals and Provincial and Federal transit and climate change actions plans. | • Support of Regional and City livability goals<br>• Support of Provincial and Federal transit and climate change action plans<br>• 2021 population and employment within 500 m of stations |
| | *Consistency with UBC's plans and policies* | *The proposed system's support of on-going and future academic, community, and research work at UBC.* | • *Ability to meet UBC's academic, community, and research targets and goals* |

| | **Evaluation Criteria** | **Description of Criteria** | **Key Indicators (Data to Collect and Report On)** |
|---|---|---|---|
| | Ability to generate positive land use changes | The ability of the proposed system to attract desired development, reduce commercial turnover, support existing development, *and achieve transit-supportive densities.* | • Ability to attract desired development, reduce commercial turnover, support existing development, as measured by the proximity to compatible land uses, existing employment centres, etc.<br>• *Ability to achieve the minimum rapid transit-supportive density requirements in 2021, as measured by comparing the station areas' 2021 estimated densities with the minimum recommended transit-supportive densities* |
| | Effects of construction on community | The potential for sidewalk, road, and bicycle lane closures during construction, and impact on vehicular traffic (along the transit corridor, north-south intersecting roads, and alternate routes), parking, local businesses, and utility systems during construction. | • Extent of sidewalk, road, and bicycle lane closures and impact on vehicular traffic<br>• Impact on parking<br>• Impact on local businesses<br>• *Impact on existing utility systems* |
| | Duration of construction[2] | The total length of time between the start and completion dates of the project. | • Duration of construction for entire project |
| | Operational effects on vehicular traffic | The effects on vehicular traffic (including transit) along north-south intersecting roads, and on alternate routes where traffic may be diverted during system operation. | • Total vehicle delay (from EMME and/or Microsimulation)<br>• Traffic diverted to alternate routes (from EMME and/or Microsimulation)<br>• Ability of alternate arterial routes to accommodate displaced traffic (level-of-service or velocity/capacity ratio)<br>• Level-of-service (LOS) on streets with construction<br>• LOS on north-south intersecting roads<br>• Number of access restrictions to adjacent properties<br>• Number of streets with restricted turning properties |

[2] It should be noted that this factor is not necessarily dependant on the technology type. It may depend more on how the project is negotiated and phased.

| | Evaluation Criteria | Description of Criteria | Key Indicators (Data to Collect and Report On) |
|---|---|---|---|
| | Contribution to the pedestrian and bicycle environment *and to community cohesion* | The effect the proposed system will have on the pedestrian and bicycle environment, *and its ability to contribute positively to the public realm and facilitate positive interactions among community residents and visitors.* | • Width and condition of sidewalks<br>• *Potential to include public art*<br>• *Emphasis on the human scale*<br>• *Overall attractiveness of the public realm*<br>• *Presence of mixed land use*<br>• *Presence of cycling infrastructure*<br>• Effects on existing bike traffic |
| | Contribution to noise environments | The effect the built system will have on the noise environment due to reduced traffic and operation of the proposed system. | • Number of autos along the transit corridor against a base case of no rapid transit<br>• Expected noise levels at specific locations along the transit corridor |
| | *Impact on First Nations* | *The impact of the proposed system on First Nations communities.* | • *Impacts to First Nations' lands*<br>• *Ability to meet First Nations' community goals* |
| | Cultural/ heritage impacts | The ability to preserve cultural and heritage buildings, trees, and spaces. | • Impacts to heritage properties/buildings/sites<br>• Impacts to culturally significant properties/buildings/sites |
| | *Practicality and public acceptability* | *The feasibility and anticipated public support of the proposed system.* | • *Feasibility and anticipated public support of the proposed system, considering the health of the economy, cost of the system, and the disruption the construction and operation would pose on local businesses* |
| **ENVIRONMENT** | Geotechnical conditions and construction-related issues | The impacts of construction on soil integrity. | • Impacts to soil integrity |
| | Effect on mode split | Mode split compared to targets of 38% for Central Broadway and 36% for UBC. | • Mode split compared to targets of 38% for Central Broadway and 36% for UBC |
| | Impacts on biodiversity | The impact on flora and fauna and their habitats. | • Impact to wildlife<br>• Impact to plant life<br>• Impact to green space |

| | Evaluation Criteria | Description of Criteria | Key Indicators (Data to Collect and Report On) |
|---|---|---|---|
| | Impacts on hydrology and aquatic habitats | The impact on storm and ground water during the construction and service life of the proposed system. | • Storm and ground water pollution during construction<br>• Reduction of storm and ground water pollution during service life<br>• Construction impacts on ground, storm, and surface water quantity and flow |
| | *Air pollutants generated from construction* | *The air emissions generated from concrete production and from the use of electricity and fossil fuels during construction.* | • *NOx emissions (tonnes)*<br>• *SOx emissions (tonnes)*<br>• *PM10 emissions (tonnes)*<br>• *Greenhouse gas emissions ($CO_2$) (tonnes)* |
| | Air pollutants reduced/added during operation | The net air emissions reduced or added during the system's service life. | • NOx emissions *(tonnes)*<br>• SOx emissions *(tonnes)*<br>• PM10 emissions *(tonnes)*<br>• Greenhouse gas emissions ($CO_2$) *(tonnes)* |
| | *Resources consumed for concrete production* | *The amount of raw materials extracted and resources consumed for the production of cement and concrete.* | • *Volume of limestone and shale consumed (tonnes)*<br>• *Volume of sand and gravel consumed (tonnes)*<br>• *Volume of water consumed (tonnes)* |
| | *Preservation of agricultural lands* | *The impact on agricultural lands.* | • *Area of agricultural lands affected* |
| SYSTEM OPERATION | System flexibility, reliability, and expandability, and durability | The proposed system's ability to integrate with a future north-south transit line, to expand to meet future demand, and to respond to vehicle problems. | • Ability to integrate with a future north-south transit line<br>• Ability to expand the system (with additional capacity and/or stations) to meet future demand<br>• *Ability to gain operational efficiencies with the initial introduction of the UBC Line*<br>• Ability to be respond quickly to vehicle problems and restore service<br>• *Travel time variability* |

For the sake of brevity, in the section below, only those criteria and indicators that have been added to the MAE framework or modified by this study are described.

The financial account examines the revenue and expenditure implications of the alternatives from the perspective of the transit agency and directly affected municipalities (in this case, TransLink and the City of Vancouver), and includes the following new criteria.

- *Cost of traffic services* is the cost to provide policing, emergency response, planning, law courts, street lighting, and parking enforcement. Although this indirect cost imposes real financial burdens on transit agencies and municipalities, it is often left out of transit project evaluations.
- *Ability to generate land value-capture revenue* is defined as a system's potential to attract development to the station areas and system corridor, and its ability to raise public funds by capturing a portion of the land value premiums. Consideration is given to whether current regulations are support of this and the proposed system's propensity to attract development. This is an important attribute to examine as transit agencies, including TransLink, are constantly being challenged to find long-term funding sources. Furthermore, under the *South Coast British Columbia Transportation Authority Act* (Provincial Government of BC, 1998), it appears that TransLink has the authority to acquire and develop lands in support of the regional transportation system, although these powers are still not yet defined. Therefore, TransLink may be able to use land-value capture funding tools to finance their operations in the future.

The customer service account, which looks at the net benefit customers or users gain from the alternatives, includes the following new criteria.

- *User charge* refers to the fare paid by passengers to use the new system.
- *Impact of modified bus system on users* investigates the number of bus routes removed or modified, and the effects this may have on passengers who may want to use buses to make short local trips. This is a response to Richmond's (2001) advice to examine the effects a new transit project will have on the whole transit system.
- *Traffic congestion reduction benefits* measure the reduced external cost a vehicle imposes on other motorists, and is determined by comparing the alternative cases to the base case. This is an effect that Litman (2008a) has identified to be significant but often missing from evaluations.
- *Station accessibility* is the ease with which the station can be accessed by all types of users. Indicators include the presence of accessibility-enhancement features (e.g., level-boarding, sufficient room for a wheelchair to maneuver in and around the station, and pavement and signage treatments), and platform location in relation to the sidewalk.
- *Susceptibility to crime* is the effect the proposed system design has the users' personal sense of security. This is measured by the presence/lack of features such as: visibility of the stations in relation to surface traffic; presence/lack of video surveillance; and presence/absence of a driver or operator inside the vehicle.
- *Effect on personal physical fitness* examines the likelihood the proposed system will promote physical activity. This important measure of health is not included in any of the other criteria or accounts in the MAE framework. It is determined by examining the proposed system's ability to attract service amenities within a 500 m walking distance of the stations, which allows users to easily access these amenities by active modes of transportation.
- *Diversity of trip needs met* examines the proposed system's ability to serve users making longer trips (e.g., from a point east of Commercial Dr. to UBC), as well as those making shorter local trips (e.g., Main St. to Macdonald St., and Main St. to Cambie St.). This is determined by comparing the time spent in transit vehicles with the time spent accessing the station platforms.

Within the economic development account, which looks at the nature, magnitude and significance of the income and employment effects of different alternatives, no new criteria have been added. Furthermore, as most economic evaluations have been able to thoroughly analyze the economic development effects of new projects, this study has chosen to leave them out of the UBC Line pilot evaluation.

Meanwhile, the following six new criteria have been added to or modified for the social and community account, which examines the alternatives' effect on the social fabric and values of directly affected communities.

- *Consistency with UBC's plans and policies* is determined by examining the proposed system's ability to meet the university's academic, community, and research targets and goals.
- *Ability to generate positive land use changes* consists of two indicators: the likelihood the proposed system will attract desired development, reduce commercial turnover, and support existing development; the ability to achieve transit-supportive densities. The first indicator is measured by the proximity of the transit corridor to compatible land uses, existing employment centres, etc. The latter indicator is determined by comparing the station areas' 2021 estimated densities with the minimum recommended transit-supportive densities. It is important to recognize that these indicators, along with ridership (from the customer service account) and the pedestrian and bicycle environment (further expanded below), all affect the success of local businesses. Therefore, the results of these evaluations should not be simply added together.
- *Effects of construction on community*, which is a criterion included in the 1999 Broadway Corridor study, examines the sidewalk, road, and bicycle lane closures that may occur during construction. It also considers the impact construction would have on vehicular traffic (along the transit corridor, north-south intersecting routes, and alternate routes where traffic may be diverted), parking, local businesses, and the existing utility systems.
- *Contribution to the pedestrian and bicycle environment and to community cohesion* looks at the effect the proposed system will have on the pedestrian and bicycle environment, as well as its ability to contribute positively to the public realm and facilitate positive interactions among community residents and visitors. Indicators for this criterion include: width and condition of sidewalks; potential to include public art; emphasis on the human scale; overall attractiveness of the public realm; presence of mixed land use; presence of cycling infrastructure; and effects on existing bike traffic.
- *Impact on First Nations* examines how the proposed system would affect First Nations' lands and community goals.
- *Practicality and public acceptability* is an assessment of the feasibility and anticipated public support of the proposed system. Consideration is given to the health of the economy, cost of the system, and the disruption that would be imposed on local businesses and residents during construction and throughout the service life.

The next account where new criteria have been added is the environmental account, and they include the following.

- *Air pollutants generated from construction* looks at the air emissions generated from concrete production (further explained below), as well as from the use of electricity and the burning of fossil fuels during construction. The last indicator has been left out of previous MAEs, including the Canada Line and Evergreen Line studies, albeit environmental impact assessments have identified this to be a potential health hazard for local communities. Pollutants measured include: nitrogen oxides (NOx); sulphur oxides (SOx); particular matter with sizes of 10 microns and smaller and therefore harmful to the respiratory tract when inhaled (PM10); and greenhouse gases emissions (expressed in carbon dioxide equivalents).

- *Resources consumed for concrete production* estimates the volume of natural resources consumed for the production of cement and concrete. Indicators include the volume of limestone, shale, sand, gravel, and water consumed. This criterion, as well as the one mentioned above, has been added to the MAE framework as concrete is one of the most environmentally detrimental construction materials. The production of one tonne of Portland cement, a component of concrete, results in one tonne of greenhouse gases being released due to the calcination of raw materials and combustion of fossil fuels (EcoSmart Concrete, 2009). As well, during cement and concrete production, emissions of NOx and PM10 are generated and large volumes of water are consumed. Furthermore, the main component of concrete is gravel or crushed stone (*Ibid),* which is mined from places such as the Fraser River, home to the greatest salmon run in the world. Such mining activities have major impacts on ecosystems and watersheds. Considering that there are many major projects within the Metro Vancouver that require concrete such as the Olympic 2010 venues, the Gateway Project and the Canada Line, it is expected that the issue of gravel "will become dramatically more valuable and contentious" (Pollon, 2006) in coming years. Yet despite these negative impacts, the use of concrete has always been left out of MAE studies.
- *Preservation of agricultural lands* looks at the size of the proposed system's footprint on agricultural lands.

Lastly, two new indicators have been added to the system operation account, both of which measure *system reliability* – ability to gain operational efficiencies with the initial introduction of the UBC Line and travel time variability. The first indicator takes into account the extent to which the current infrastructure (fleet vehicles, maintenance facilities, etc.) will be used by the UBC Line. The second indicator examines the likelihood that the proposed system's travel times will fluctuate due to traffic congestion, collisions or other incidents.

# 4. The UBC Line Case Study

This chapter provides a detailed description of the measurement techniques and results of the UBC Line pilot evaluation. It begins by describing the design concepts used in this study for the SkyTrain and LRT options. This is followed by five subsections - one for each evaluation account included in this case study. In each subsection, the steps used to measure the various indicators are described, and the sources of data and information gaps are identified. The results of the pilot evaluation are also presented in five individual tables and the major findings are highlighted within the text. In the last section of the chapter, the main strengths of each technology are summarized.

## 4.1 System Design Concepts

The following are descriptions of the LRT and SkyTrain system design concepts used in this pilot evaluation. A summary of these design concepts is also shown in Table 4-1.

*Light Rail*


**Figure 4-1: Proposed LRT route and station locations**
(Modified image of an original from the 1999 Broadway Corridor study)

- The tracks are at-grade and lie mainly in the centre of the roadway along Broadway from Commercial Dr to Alma St., and along W.10$^{th}$ Ave. from Alma St to Blanca St., and along University Boulevard from Blanca St. to UBC's new transit hub (Figure 4-2 shows examples of median-alignment tracks).

**Figure 4-2: Examples of light rail systems operating in median lanes.**
Source: Oregon and Washington State DoT (2009)

- The stations are located at Commercial Dr., Clark St., Fraser St., Main St., Cambie St., Oak St., Granville St., Arbutus St., MacDonald St., Alma St., Sasamat St., and at UBC's new transit hub, which will replace the temporary bus exchange currently being used at UBC (a map of the proposed LRT line is shown in Figure 4-1).
- The LRT line is approximately 13.4 km in length.
- Wheelchair-accessible, raised platforms are located between the two railway tracks to allow for level-boarding.
- The vehicles are low-floor, electrically-powered rail cars (similar to the Siemens SD70 cars, which are now used in the Portland LRT system) that can operate singularly or in multiple units on double tracks (see Figure 4-3). In this study, it is assumed that each train will have 3 cars.

**Figure 4-3: Portland's new light rail trains.**
Source: TriMet (2009a).

- Pedestrian activated signals are converted to full traffic signals. To prevent uncontrolled crossing of LRT tracks, minor unsignalized streets and mid-block access driveways become right-in/right-out only.
- For other traffic, two continuous through travel lanes are available each way. Left turn lanes are provided at major intersections.
- At signalized intersections, the trains receive priority with the use of traffic signal prioritization measures so that signals are advanced or held to allow trains to proceed without considerable delay.
- A mountable curb is used to prevent other vehicles from encroaching on the LRT tracks.
- An off-board fare collection process allows passengers to board through all doors.
- At all stations, on-street parking is removed. In many sections along Broadway parking is eliminated or reduced to one side of the street. In addition to providing more road space, this also serves as a car restriction policy. Other landscape buffers are installed to protect pedestrians from vehicular traffic.
- At station areas, the curb lanes and/or sidewalks are narrowed to accommodate the station platforms.
- Bike storage is available at stations.
- Service frequency is: 4-5 minutes during peak hours and mid-day; 5-6 minutes in the early morning and evening; 6-8 minutes during the late evening, and on Saturdays, Sundays, and holidays.
- Hours of operation are:
    - Monday to Saturday: 5:00 am to 2:30 am
    - Sunday and holidays: 6:00 am to 2:00 am
- Average speed of the system is 28 km/hour (excluding station stops) and the average travel time is as follows:
    - UBC to Commercial Dr.: 32 minutes
    - Granville to Commercial Dr.: 13 minutes
    - Cambie to Commercial Dr.: 8 minutes

- The maximum capacity per train is 516 passengers and the maximum number of passengers that can pass through a single point within an hour is 6880.

*SkyTrain*


**Figure 4-4: Proposed SkyTrain route and station locations.**
(Modified image of an original from the 1999 Broadway West study)

- The SkyTrain extension begins at the Vancouver Community College (VCC)/Clark station and proceeds west into the Great Northern Way Campus to a below-grade station. The tracks then swing south, passing below Great Northern Way and follow Prince Edward St. in an underground tunnel. The alignment remains below grade and heads west upon reaching E.10th Ave. until UBC. There are entrances and exits at the surface level along Broadway.
- The stations are located at VCC/Clark, Great Northern Way Campus, Fraser St., Main St., Cambie St., Oak St., Granville St., Arbutus St., MacDonald St., Alma St., Sasamat St., and at UBC's new transit hub (a map of the SkyTrain line is shown in Figure 4-4).
- The SkyTrain extension is approximately 13.4 km in length.
- The existing SkyTrain technology is used (see Figure 4-5). More Mark II cars are added to the fleet and 4- or 5-car trains are utilized during peak hours.
- The rail line is constructed using the bored tunneling technique (see Figure 4-6), and the tunnel is deeper than the Canada Line to avoid utilities.
- The current off-board fare collection process is continued, allowing passengers to board through all doors.
- Current on-street parking is retained along Broadway.
- Bike storage is available at stations.

**Figure 4-5: Old and new Mark II SkyTrain cars.** Source: Pabillano (2009).

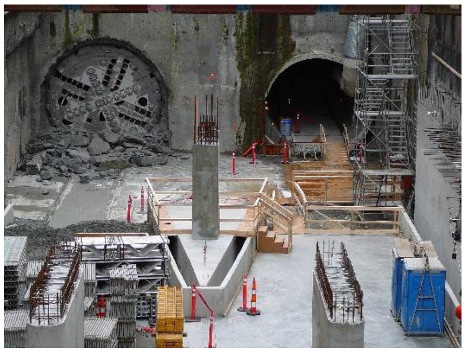

**Figure 4-6: Canada Line tunnel boring machine at work in Downtown Vancouver.** Source: InTransitBC (2009).

- Service frequency is: 2-3 minutes during peak hours; 4-6 minutes in the early morning, mid-day, and evening; 6-8 minutes during the late evening, and on Saturdays, Sundays, and holidays.
- Hours of operation are:
    - Monday to Friday: 5:00 am to 1:30 am
    - Saturday: 6:00 am to 1:30 am
    - Sunday and holidays: 7:00 am to 12:30 am
- Average speed of the system is 42 km/hour (excluding station stops) and the average travel time is as follows:
    - UBC to Commercial Dr.: 23 minutes
    - Granville to Commercial Dr.: 9 minutes
    - Cambie to Commercial Dr.: 6 minutes
- The maximum capacity per train is 468-585 passengers and the maximum number of passengers that can pass through a single point within an hour is 11,232 to 14,040.

**Table 4-1: Summary of the LRT and SkyTrain system design concepts**

| Attribute | LRT | SkyTrain |
|---|---|---|
| **Alignment** | At-grade, along median lanes of Broadway (until Alma St.), W. 10th Ave. (between Alma St. and Blanca St., and University Boulevard (west of Blanca St.) | Almost all underground, except between VCC/Clark station and the Great Northern Way Campus station. |
| **Station Locations** | Commercial Dr., Clark St., Fraser St., Main St., Cambie St., Oak St., Granville St., Arbutus St., MacDonald St., Alma St., Sasamat St., and UBC's new transit hub | Great Northern Way Campus, Fraser St., Main St., Cambie St., Oak St., Granville St., Arbutus St., MacDonald St., Alma St., Sasamat St., and UBC's new transit hub |
| **System Length** | 13.4 km | 13.4 km |
| **Platform Location** | At-grade, between the two railway tracks | Underground |
| **Vehicle Type** | Low-floor, electrically-powered rail cars that can operate singularly or in multiple units on double tracks | Existing SkyTrain technology |
| **Fare Collection Process** | Off-board fare collection | Off-board fare collection |
| **Street Parking** | At all stations, on-street parking is removed. In many sections along Broadway parking is eliminated or reduced to one side of the street. | Existing street parking retained |
| **Bike Storage** | Bike storage will be available at stations | Bike storage will be available at stations |
| **Service Frequency** | • 4-5 minutes during peak hours and mid-day<br>• 5-6 minutes in the early morning and evening<br>• 6-8 minutes during the late evening, and on Saturdays, Sundays, and holidays | • 2-3 minutes during peak hours<br>• 4-6 minutes in the early morning, mid-day, and evening<br>• 6-8 minutes during the late evening, and on Saturdays, Sundays, and holidays. |

| Attribute | LRT | SkyTrain |
|---|---|---|
| **Hours of Operation** | • Monday to Saturday: 5:00 am to 2:30 am<br>• Sunday and holidays: 6:00 am to 2:00 am | • Monday to Friday: 5:00 am to 1:30 am<br>• Saturday: 6:00 am to 1:30 am<br>• Sunday and holidays: 7:00 am to 12:30 am |
| **Average Speed (excluding station stops)** | 28 km/hour | 42 km/hour |
| **In-Vehicle Travel Time** | • UBC to Commercial Dr.: 32 minutes<br>• Granville to Commercial Dr.: 13 minutes<br>• Cambie to Commercial Dr.: 8 minutes | • UBC to Commercial Dr.: 23 minutes<br>• Granville to Commercial Dr.: 9 minutes<br>• Cambie to Commercial Dr.: 6 minutes |
| **Maximum Capacity per Train** | 516 passengers | 468-585 passengers |

Before describing the evaluation techniques and results of this case study, it is worth noting that BRT is another viable option to consider for this corridor. The only reason that two types of rapid transit technologies have been selected for this case study and BRT has been left out is to keep the project scope within feasible limits.

## 4.2 Evaluation Techniques and Results

To develop appropriate evaluation techniques and to identify realistic assumptions that can be utilized for the LRT and SkyTrain evaluations, numerous other rapid transit systems from across North America have been reviewed. These include the existing B-Lines that operate along Broadway, the Millennium and Expo SkyTrain Lines, the anticipated Canada and Evergreen Lines, Portland's streetcar and light rail lines, and other rapid transit systems in North America. As well, general local experience with regards to public transit has also been used when developing the assumptions.

In addition, the literature cited in Chapter 2 has been taken into account in the development of the evaluation techniques. However, as all monetary inputs and results are expressed in 2009 Canadian dollars and as there is only one target year in the evaluations, no discount factors are applied.

At this time, it is essential to note that the full benefits of the UBC Line will not be achieved in 2021. Therefore, a full MAE for the UBC Line should include another target year further into the future (e.g., 2040). Those criteria that should include a further target year are marked with an asterisk in Tables 4-2 to 4-6.

### 4.2.1 Financial Account

Table 4-2 provides a summary of the evaluation results for the financial account.

**Table 4-2: Evaluation results for the financial account**

| Evaluation Criteria | Key Indicators | LRT | SkyTrain |
|---|---|---|---|
| **a. Capital Cost ($2009)** | i. Total capital cost | $550-800 million | $2.2-2.8 billion |
| | ii. Capital cost per passenger km | $0.50 | $1.08 |
| | iii. Capital cost per new passenger (based on ridership levels in 2021) | $25-36 | $85-109 |
| **b. Operating Cost in 2021 ($2009)*** | i. Total annual operating cost | $63.4 million | $26.1 million |
| | ii. Annual operating cost per service hour | $231 | $89 |
| | iii. Annual operating cost per passenger | $1.62 | $0.61 |
| | iv. Annual operating cost per new passenger relative to base case | $2.89 | $1.01 |
| **c. Operating Revenue in 2021 ($2009)*** | i. Total gross annual revenue | $73.8 million | $81 million |
| | ii. Gross annual revenue per passenger | $1.89 | $1.89 |
| ***d. Cost of Traffic Services ($2009)**** | *i. Annual cost of providing policing, emergency response, law courts, street lighting, and parking enforcement* | *$653,500* | *$693,500* |
| ***e. Ability to Generate Land Value-Capture Revenue*** | *i. Potential to generate land value-capture funding* | *High potential* | *High potential* |
| **f. Benefits and costs of reduced parking** | i. Annualized savings of not having to provide parking spaces ($2009) | $263/stall | $0 |
| | ii. Annualized reduction in parking fees collected ($2009) | $3500/stall | $0 |

### *a. Capital Cost*

Indicator i: Total capital cost
Indicator ii: Capital cost per passenger kilometre
Indicator iii: Capital cost per new passenger (based on ridership levels in 2021)

*Data Sources*

- Cost per system kilometre information for light rail systems in Sacramento, Denver, Pittsburgh, Los Angeles, Dallas, Calgary, Edmonton, and Buffalo (which ranged between $8 and 77 million/system km in 2008 US dollars) from Condon et al. (2008).
- Approximate cost per system kilometre to build the Evergreen Line, using the Southeast alignment and a mostly at-grade LRT system design, from IBI Group (2004).
- Total capital cost for SkyTrain from the *Provincial Transit Plan* (Provincial Government of BC, 2008).

- Capital cost per passenger kilometre for LRT and SkyTrain, from Condon and Dow's 2008 report, *A Cost Comparison of Transportation Modes.* The LRT estimate is based on St. Louis' LRT system (data from the National Transit Database), and the SkyTrain estimate is based on values provided in the *Evergreen Line Rapid Transit Project Business Case* (TransLink, 2008b).
- Ridership data (see indicator a)ii) in Subsection 4.2.2).

*Approach*

- Adopt the cost per system kilometre of the light rail systems mentioned above, and consider the results of the Evergreen Line MAE, which indicated that local at-grade LRT systems tend to be more expensive to build (approximately $60 million/system km).
- Multiply the cost/system kilometre with the length of the line (13.4 km) to get the total capital cost for LRT.
- Adopt the total capital cost of the SkyTrain mentioned above and consider the fact that using the bored tunneling technique will increase system cost.
- Adopt the capital costs per passenger kilometre calculated by Condon and Kow (2008) for LRT and SkyTrain. The capital costs were calculated using construction and vehicle costs amortized over the expected life of the systems and vehicles. These annualized costs were then divided by the annual passenger-km of each mode.
- Divide the total capital costs by the expected number of new riders relative to the base case.
- Convert all values into 2009 Canadian dollars.

*Results*

The total capital cost for LRT is estimated to be between $550 and $800 million while the SkyTrain capital cost will be between $2.2 and $2.8 billion. The cost per passenger kilometre will be about $0.50 for LRT and $1.08 for SkyTrain, and the cost per new passenger will be $25-36 for LRT and $85-109 for SkyTrain. The significantly higher cost of the SkyTrain alternative is attributed to a number of factors, including the geotechnical studies, deep underground tunneling, and removal of underground utilities at station areas that would be required, as well as the construction of the underground stations and tunnel. See Appendix C for the sensitivity analysis that illustrates how the capital costs would be affected by changes to the population growth scenarios, vehicle operating costs, bus service levels, mode share of walking and cycling trips, construction costs, and construction methods (the last factor is only applicable to SkyTrain).

*Data Gaps and Challenges*

Presently, modeling has not yet been done to estimate the passenger-kilometres for the LRT and SkyTrain options. Thus, the capital cost per passenger kilometre values had to be adopted from Condon and Dow's 2008 report. To help refine these values, modeling should be done during the full MAE analysis.

### *b. Operating Cost in 2021*

Indicator i: Total annual operating cost
Indicator ii: Annual operating cost per service hour
Indicator iii: Annual operating cost per passenger
Indicator iv: Annual operating cost per new passenger relative to base case

*Data Sources*

- 2007 SkyTrain operating cost per revenue vehicle hour, from BC Rapid Transit Co. Ltd. (2008).
- 2007 operating cost per revenue vehicle hour for a total of twenty-one LRT systems in the US, from the Federal Transit Administration's National Transit Database (see Appendix B for a complete list of the light rail systems included in the analysis) (2008).

*Approach*

- Calculate the average operating cost per revenue vehicle hour for the reference LRT systems listed in Table B-1.
- Adopt the 2007 operating cost per revenue vehicle hour for LRT (using the average of the twenty-one reference systems) and SkyTrain, and convert the values into 2009 Canadian dollars.
- Calculate the total service hours in 2021 using the assumed hours of service and headways described in Section 4.1 for the LRT and SkyTrain systems (see Appendix B for the detailed methodology).
- Multiply the total service hours in 2021 by the operating cost per vehicle revenue hour to yield the total operating cost for the LRT and SkyTrain options.

*Results*

The total annual operating cost is $63.4 million for LRT and $26.1 million for SkyTrain. The operating cost per service hour is approximately $231 for LRT and $89 for SkyTrain. Thus, the operating cost per passenger is $1.62 for LRT and $0.61 for SkyTrain. Lastly, the operating cost per new passenger relative to the base case is $2.89 for LRT and $1.01 for SkyTrain. See Appendix C for the sensitivity analysis that illustrates how the operating costs would be affected by changes to the population growth scenarios, vehicle operating costs, bus service levels, mode share of walking and cycling trips, and the service frequency and operating hours of the UBC Line.

### *c. Operating Revenue in 2021*

Indicator i: Total gross annual operating revenue
Indicator ii: Gross annual operating revenue per passenger boarding

*Data Sources*

- Ridership data (see indicator a)i) in Subsection 4.2.2)
- Operating revenue data for 2007 from TransLink's *2007 Annual Report*.

*Approach*

- Adopt the operating revenue per passenger boarding for 2007 and convert the value into 2009 Canadian dollars.
- Multiply the number of annual boardings projected for 2021 by the operating revenue per passenger boarding.

*Results*

The gross annual operating revenue in 2021 is approximately $73.8 million for LRT and $81 million for SkyTrain. The gross annual operating revenue per passenger boarding is $1.89 for both LRT and SkyTrain as the fare structure is expected to be the same for both modes. See Appendix C for the sensitivity analysis that illustrates how the operating revenues would be affected by changes to the population growth scenarios, vehicle operating costs, bus service levels, mode share of walking and cycling trips, and the service frequency and operating hours of the UBC Line.

*Data Gaps and Challenges*

The operating revenue gained solely from the operation of the UBC Line is difficult to determine as passengers may also be using other parts of the transit system with the same fare. Therefore, it can only be concluded that the actual operating revenue attributed to the UBC Line is lower than what has been calculated here.

### *d. Cost of Traffic Services*

Indicator i: Annual cost of providing policing, emergency response, law courts, street lighting, and parking enforcement

*Data Sources and Approach*

- Estimated traffic services cost per mile for passenger vehicles and buses in 2007 US dollars, from Litman (2009b).
- Transform the above conversion factor into 2009 Canadian dollars per kilometre.
- Compute the cost of traffic services for the base case, as well as for the LRT and SkyTrain scenarios by multiplying the 2021 annual vehicle kilometres traveled along Broadway (see Appendix B for the methodology used to calculate this) by the adjusted traffic cost conversion factor.

*Results*

The cost of traffic services is approximately $653,500 per year for the LRT option and $693,500 per year for the SkyTrain option. See Appendix C for the sensitivity analysis that illustrates how the cost of traffic services would be affected by changes to vehicle operating costs, bus service levels, and the mode share of walking and cycling trips.

*Data Gaps and Challenges*

Actual data on vehicle kilometres traveled along the Broadway Corridor is unavailable. Thus rough estimates were generated using traffic volume data collected by the City of Vancouver at several points along the Corridor. The traffic counts, however, were conducted across several years and different locations were chosen each year. As a result, there may be inconsistencies in the data.

In addition, the conversion factors used to determine the cost of traffic services do not take into account Vancouver's local conditions. Further work should be conducted to tailor the conversion factors so that local circumstances are taken into consideration.

### *e. Ability to Generate Land Value-Capture Revenue*

Indicator i: Potential to generate land value-capture funding

*Data Sources*

- Literature sources on value-capture financing (see Chapter 2, Section 2.4).
- *South Coast British Columbia Transportation Authority Act* (Provincial Government of BC, 1998).
- Typical distance that pedestrians are willing to walk to access daily amenities, from the City of Calgary's *Transit-Oriented Development: Best Practices Handbook*: 500 m or a five-minute walk.

*Approach*

- Rate each option's ability to generate land value-capture funding at the stations and/or along the Corridor using the following high-medium-low scale:
    - Low = the system design has little propensity to attract development to its stations or along its route;
    - Medium = the system design has a high propensity to attract development to its stations and/or along its route, however, current regulations do not allow transit agencies to capture the land value premiums; and
    - High = the system has a high propensity to attract development to its stations and/or along its route and current regulations may allow transit agencies to capture the land value premiums or develop lands to support transit.

*Results*

Under the *South Coast British Columbia Transportation Authority Act,* it appears that TransLink may have the authority to acquire and develop lands in support of the regional transportation system, although these powers are still not yet defined. Therefore, it is possible that land value-capture financing could be used by TransLink in the future to fund its operations, whether light rail or SkyTrain technology is applied (as Parson Brinkerhoff's 2001 study mentioned, the influence on property values appear to be more dependent on the reliability, frequency, and speed of the service than on the type of rapid transit technology). As the average distance between the stations will be 1 km for both the Corridor. Development at station areas, however, may be more intensive.

### *f. Benefits and Costs of Reduced Parking*

Indicator i: Annualized savings of not having to provide parking space
Indicator ii: Annualized reduction in parking fees collected

*Data Sources*

- 2007 and 2008 annual revenues from metered parking along Broadway, from the City of Vancouver (personal communication, May 25, 2009).
- Cost to maintain and operate parking meters along Broadway in 2007 and 2008, and number of on-street parking stalls along Broadway, from the City of Vancouver (personal communication, May 25, 2009).

*Approach*

- Adopt the 2007 and 2008 annual parking revenue, and maintenance and operations cost data from the City of Vancouver and convert the values into 2009 dollars.
- Assume that some of the on-street parking along the Corridor will be removed for the LRT option and that all existing on-street parking along the Corridor will be retained for the SkyTrain option.

*Results*

With on-street parking removed along the Corridor to accommodate light rail tracks, there is an annualized savings of $263/stall, and an annualized reduction of $3,500/stall in parking revenue collected by the City of Vancouver. In comparison, for the SkyTrain option, there are no significant changes to the City of Vancouver's parking revenue or expenditures. Yet if the City decides to implement a different streetscape policy for the Corridor, this may change (i.e., there could be an increase or decrease in the amount of on-street parking provided).

### 4.2.2 Customer Service Account

Table 4-3 provides a summary of the evaluation results for the customer service account.

**Table 4-3: Evaluation results for the customer service account**

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| **a. Ridership*** | i. Boardings in 2021 | 39 million | 42.9 million |
| | ii. Boardings new to transit in 2021 relative to base case | 21 million | 25.8 million |
| ***b. User Charge*** | *i. Fare schedule* | *Zonal structure, integrated with existing bus and SkyTrain system* | |
| ***c. Impact of Modified Bus System on Users*** | *i. Bus routes removed or modified* | *Removed: #99 B-Line and #84<br>Unaltered: #8, #9 and #16<br>Modified: #17 reduced and north-south intersecting bus service would increase* | |
| | *ii. Effects of bus modifications on passengers who want to use buses to make short local trips* | *Longer wait times for local bus service along the Corridor, but enhanced local service along north-south intersecting bus routes* | |
| ***d. Traffic Congestion Reduction Benefits* ($2009)*** | *i. Net reduction in congestion cost relative to base case* | *$557,000* | *$440,000* |
| ***e. Station Accessibility*** | *i. Presence of accessibility-enhancement features* | *Both systems will include accessibility-enhancement features* | |
| | ii. Platform location in relation to sidewalk | Medium to high accessibility | Low accessibility |
| ***f. Susceptibility to Crime*** | *i. Presence/lack of system design features that affect users' personal sense of security* | *Both systems will include features that increase users' sense of personal security* | |
| ***g. Effect on Personal Physical Fitness**** | *i. Ability to attract service amenities within a 500 m walking distance of the stations* | *Both systems will promote physical activity as they will have a high propensity to attract service amenities within 500 m of the stations* | |
| ***h. Diversity of Trip Needs Met*** | *i. System performance for long trips (e.g., from a point east of Commercial Dr. to UBC)* | *Medium performance for long trips* | *High performance for trips beginning along the existing Millennium Line and ending in Vancouver's west side. Medium performance for trips beginning elsewhere* |
| | *ii. System performance for shorter local trips (e.g., from Main St. to MacDonald St., and from Main St. to Cambie St.)* | *Medium performance for short trips (e.g., Main St. to Macdonald St.). High performance for even shorter trips (e.g., Main St. to Cambie St.)* | *Medium performance for short trips (e.g., Main St. to Macdonald St.). Low performance for even shorter trips (e.g., Main St. to Cambie St.)* |

### *a. Ridership*

Indicator i: Passenger boardings in 2021
Indicator ii: Passenger boardings new to transit in 2021 relative to base case

*Data Sources*

- UBC Office of Planning and Institutional Research (2008), UBC Campus and Community Planning (2005, 2007, and 2009), the *UBC Comprehensive Community Plan* (Metro Vancouver, 1997), the *UBC Official Community Plan* (UBC, 2000), the UBC University Town website (n.d.), the UBC *Transportation Status Reports* (2004-2008), TransLink (2009), the City of Vancouver (2009), and Metro Vancouver (2009).
- See Appendix B for a more comprehensive list of data sources, the information they provided, and how the data was used.

*Approach*

- Apply Richmond's (2001) recommendations regarding the calculation of ridership, and develop a growth scenario that is as realistic as possible. [3]
- Calculate the unlinked ridership going to and from UBC for the base case and the LRT and SkyTrain scenarios (see Appendix B for the detailed methodology).
- Calculate the unlinked ridership not originating from or destined for UBC for the base case and the LRT and SkyTrain options (see Appendix B for the detailed methodology).
- Add the UBC and non-UBC ridership values together for the base case and the LRT and SkyTrain options (see Appendix B for the detailed methodology).
- Compare the ridership of the LRT and SkyTrain scenarios to the base case in 2021.

*Results*

The number of boardings in 2021 is 39 million for the LRT option and 42.9 million for the SkyTrain option. The number of boardings new to transit in 2021 relative to the base is 22 million and 25.8 million for the LRT and SkyTrain scenarios respectively. These increases are due to a number of factors, including the new transit capacity and travel time savings offered by the LRT and SkyTrain alternatives. As well, in the base case and in the alternative scenarios, it is assumed that the cost of fuel and parking would increase, and that UBC and the City of Vancouver would implement other transportation demand management strategies. Thus it is anticipated that new riders will be attracted to the public transit system. The differences between the LRT and SkyTrain are mainly attributed to the shorter travel times of the SkyTrain.

[3] This involves taking the following factors into account: the population projections that have been made for the area around the Corridor by the City of Vancouver and Metro Vancouver; the employment centres that are being planned around the Corridor; the fact that UBC's population will likely level off at around 2017; the fact that more people will be living at UBC by 2021; and the high probability that some of the UBC Line ridership will have been transferred from other transit routes.

See Appendix C for the sensitivity analysis that illustrates how ridership would be affected by changes to the population growth scenarios, vehicle operating costs, bus service levels, and the mode share of walking and cycling trips.


**Figure 4-7: Houston LRT station (left) and the interior of a Vancouver SkyTrain vehicle (right).**
Sources: (left) Light Rail Now (2006) and (right) Skyscraperpage.com (2009).

*Data Gaps and Challenges*

There is a lack of information on the current UBC residential population. As no inventory is kept on the number of students, faculty, and staff living on campus, estimates had to be generated using the information from various UBC planning documents. In cases where the information was inconsistent, more conservative estimates were made.

Residential and employment population projections specific to the Corridor are also unavailable. Projections only exist at the traffic area zone level, which encompasses areas other than the Corridor. An assumption had to be made that the Corridor's growth rate is the same as the growth rate of these larger zones.

Thirdly, TransLink currently does not collect linked ridership data. As a result, the ridership inputs used in this study are unlinked and the results presented are also unlinked.

***b. User Charge***

Indicator i: Fare schedule

*Data Sources and Approach*

- Discussions with TransLink staff.

*Results*

Both the LRT and SkyTrain systems will operate within the zonal fare structure that is currently applied to the bus and SkyTrain system. The cost to use the UBC Line will therefore be the same as the cost to use the current buses and SkyTrain lines. As a result, low-income individuals will not be disenfranchised by the new system.

### c. *Impact of Modified Bus System on Users*

Indicator i: Bus routes removed or modified
Indicator ii: Effects of bus modifications on passengers who want to use buses to make short local trips

*Data Sources*

- Bus route information from TransLink.

*Approach*

- Discussions with TransLink staff to determine which existing bus routes may be removed, modified, and unaltered after the UBC Line comes into operation.

*Results*

The results for both indicators are the same for the LRT and SkyTrain scenarios. The #99 B-Line and #84 express bus routes (the latter of which operates along a route parallel to Broadway) will be removed. The local bus routes #8, #9, and #16 will remain unaltered, and the local #17 bus route will only run between Cambie and Oak (instead of continuing west to UBC). The service for north-south intersecting bus routes will be increased.

As a result of the #17 local bus service (see Figure 4-8) being reduced, there will be longer wait times for those passengers wishing to use the local bus service along the Corridor (the #8 and #16 bus routes only operate along short segments of the Corridor). Local feeder service along north-south intersecting bus routes, however, will be enhanced so that the UBC Line is more accessible.


**Figure 4-8: Local #17 bus at Alma and Broadway**

### d. *Traffic Congestion Reduction Benefits*

Indicator i: Net reduction in congestion cost relative to base case

*Data Sources and Approach*

- Congestion cost per mile for passenger vehicles and buses in 2007 US dollars, from Litman (2009b).
- Transform the above conversion factor into 2009 Canadian dollars per kilometre.
- Compute the congestion cost for the base case, and the LRT and SkyTrain alternatives by multiplying the 2021 annual vehicle kilometres traveled along the Corridor (see Appendix B for the methodology used to calculate this) by the adjusted congestion cost conversion factor.
- Calculate the congestion cost savings for the LRT and SkyTrain alternatives by comparing the values to the base case scenario.

*Results*

The results show that an LRT system will have a greater potential to reduce vehicle-kilometres traveled along the Corridor than a SkyTrain system. As one road lane will be dedicated to the LRT right-of-way, the amount of space for private vehicles and the incentive to drive will be reduced. In the case of the SkyTrain, extra roadway would be freed up for private vehicles as the existing #99 B-line will be removed. Consequently, the annual congestion cost savings is $557,000 for LRT and $440,000 for SkyTrain. See Appendix C for the sensitivity analysis that illustrates how the congestion cost savings would be affected by changes to vehicle operating costs, bus service levels, and the mode share of walking and cycling trips.

*Data Gaps and Challenges*

As mentioned earlier in Subsection 4.2.1.d, actual data on vehicle kilometres traveled along the Corridor is unavailable. Rough estimates had to be generated using traffic volume data collected by the City of Vancouver at several points along the Corridor. There may, however, be inconsistencies in the data that was collected.

As well, the conversion factors used to determine the congestion costs do not take into account Vancouver's local conditions. Further work should be conducted to compute conversion factors that take local circumstances into consideration.

### *e. Station Accessibility*

Indicator i: Presence of accessibility-enhancement features
Indicator ii: Platform location in relation to the sidewalk

*Data Sources*

- Information regarding the accessibility features of light rail stations in Portland, OR and of the SkyTrain system (Expo Line, Millennium Line, and Canada Line), from the TriMet (2009), TransLink (2009), and Canada Line websites (InTransitBC, 2009).
- Previous assessment of platform location included in the 1999 *Beyond the B-Line* study.

*Approach*

- Assume the LRT and SkyTrain options for the UBC Line will have the same accessibility features found at Portland's light rail and streetcar stations, the existing SkyTrain stations, and the new Canada Line stations (e.g., level-boarding, sufficient room for a wheelchair to maneuver in and around the station, pavement and signage treatments, audio and visual cues associated with the transit service, and elevator access).
- Using the information from the 1999 study, evaluate each alternative in terms of the distance passengers have to travel to access station platforms.

*Results*


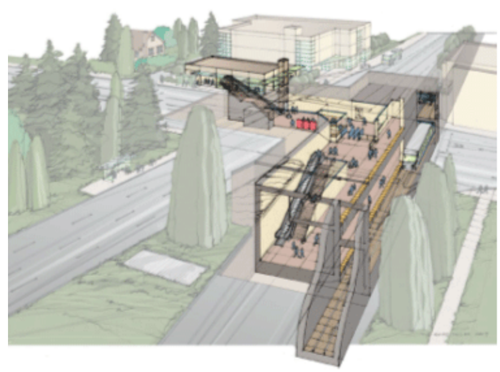

**Figure 4-9: Streetcar station in Portland, OR (left) and an illustration of an underground Canada Line station (right).** Sources: OKCTalk (2008) and InTransitBC (2009).

In the case of the LRT alternative, the use of low-floor vehicles, at-grade raised platforms (for level-boarding) with pavement and signage treatments, and audio and visual cues at the stations and inside the vehicles will enable all types of transit users to access the system (see Figure 4-9). They will not be required to go above ground or underground to access the station platforms. The width of the platforms may be narrower than ideal for wheelchair users; however, requiring building setbacks and acquiring additional right-of-way could mitigate this problem. There may also be issues with wheelchair users crossing the guideways as the wheels may get caught in the tracks. To minimize these incidents, intersection treatment options would be utilized.

In the case of the SkyTrain alternative, the underground stations will also be wheelchair accessible, and will have pavement and signage treatments and audio and visual cues. As shown in Figure 4-9, however, users will need to travel longer distances from the surface access points to the station platforms.

### *f. Susceptibility to Crime*

Indicator i: Presence/lack of system design features that affect users' personal sense of security

*Data Sources*

- Information regarding the security features of the light rail stations in Portland, OR and of the SkyTrain system (Expo Line, Millennium Line, and Canada Line), from the TriMet (2009), TransLink (2009), and Canada Line websites (InTransitBC, 2009).

*Approach*

- Assume the LRT and SkyTrain options for the UBC Line will have the same security features found at Portland's light rail stations (open concept), the existing SkyTrain stations, and the new Canada Line stations (security cameras, emergency phones, etc.).

*Results*

For the LRT alternative, the presence of a driver and the high visibility of the stations and the trains may increase users' personal sense of security. In the case of the SkyTrain alternative, although the underground stations will have security cameras and emergency phones, the lack of drivers and the low visibility of the system and stations may lower users' perceived sense of security (see Figure 4-10). This, however, could be mitigated with the presence of fare gates, which will likely be installed at the SkyTrain stations but not at the LRT stations.

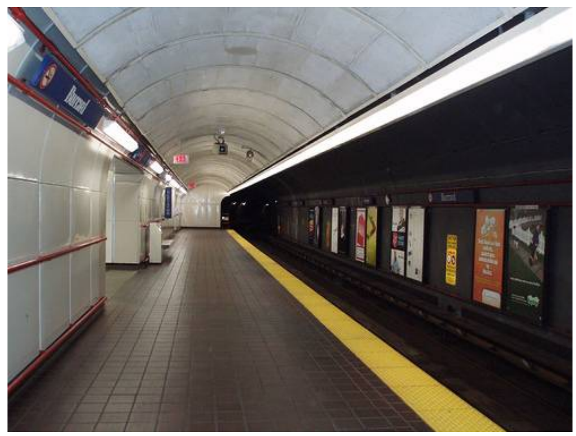

**Figure 4-10: Burrard underground SkyTrain station.** Source: Anonymous (2006).

### g. *Effect on Personal Physical Fitness*

<u>Indicator i</u>: Ability to attract service amenities within a 500 m walking distance of the stations.

*Data sources*

- Typical distance that pedestrians are willing to walk to access daily amenities (500 m or approximately a five-minute walk), from the City of Calgary's *Transit-Oriented Development: Best Practices Handbook* (2004).
- The effect of a neighbourhood's walkability on physical activity, from Frank and Kavage (2008).
- Results from the *contribution to the pedestrian and bicycle environment and to community cohesion* criterion (see Subsection 4.2.3.e).

*Approach*

- Assess each alternative's ability to promote physical activity, taking into consideration the typical distance pedestrians are willing to walk to access services, and the system's ability to promote walkable environments.

*Results*

Both the LRT and SkyTrain systems will lead to improved transit service. Therefore, as the ridership numbers have indicated, new riders will be attracted to the systems. Assuming that at least a portion of these new riders are former private vehicle users, the switch to public transit will help increase their physical activity and improve their physical fitness (see Figure 11), as a larger portion of their trip will require an active mode of transportation (e.g., walking or cycling). Furthermore, Broadway and UBC's walking paths are already well-connected, and commercial activity will likely be promoted at the LRT and SkyTrain stations as well as within a five-minute walk (or 500 m) of the stations. Transit users and the rest of the community will therefore be able to access basic services and amenities such as local grocery stores, drycleaners, restaurants, cafes, and medical clinics by foot, and reduce their dependence on automobiles. This, again, will promote physical activity and enhance physical health.


**Figure 4-11: Transit use promotes physical activity.** Source: Travel Portland (n.d.).

### *h. Diversity of Trip Needs Met*

Indicator i: System performance for long trips (e.g., a point east of Commercial Dr. to UBC)
Indicator ii: System performance for shorter local trips (e.g., Main St. to Macdonald St., and Main St. to Cambie St.)

*Data Sources and Approach*

- Using the conceptual design of the systems, analyze the LRT and SkyTrain's effectiveness in serving long and short local trips. Consideration is given to the amount of time it takes to make transfers and access the station platforms.

*Results*

For long trips where the point of origin is east of Commercial Dr. and somewhere along the current Millennium Line route, and the point of destination is on the west side of Vancouver (e.g., UBC), a SkyTrain extension along the Corridor would reduce the number of transfers required and achieve higher travel time savings than the LRT system. If, however, the point of origin of a long commute trip is not along the current Millennium Line route but still close to or east of Commercial Dr., then passengers would still need to change modes at Commercial Dr. regardless of which system is built.

In the case of shorter trips, such as from Main St. to Macdonald St., the time spent traveling to the SkyTrain platforms would offset some of the travel time savings achieved by the system. For even shorter trips, for example from Main St. to Cambie St., the time spent traveling down to the underground SkyTrain platforms would make the total travel time longer than commuting by an at-grade LRT system.

### 4.2.3 Social and Community Account

Table 4-4 provides a summary of the evaluation results for the social and community account.

**Table 4-4: Evaluation results for the social and community account**

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| ***a. Consistency with UBC's Plans and Policies*** | *i. Ability to meet UBC's academic, community, and research targets and goals* | *Strong support* | |
| **b. Ability to Generate Positive Land Use Changes*** | i. Ability to attract desired development, reduce commercial turnover, support existing development | *Highly capable* | |
| | *ii. Ability to achieve the minimum rapid transit-supportive density requirements in 2021* | *All study areas are able to achieve the minimum LRT-supportive density* | *8 out of the 10 study areas are able to achieve the minimum SkyTrain-supportive density* |
| **c. Effects of Construction on Community** | i. Extent of sidewalk, road, and bicycle lane closures and impact on vehicular traffic (along the Corridor, intersecting north-south routes, and alternate routes where traffic may be diverted) | Sidewalk – medium to high impact along the Corridor, with greatest impact where sidewalks are modified<br>Road – medium to high impact along the Corridor, with greatest impact at intersections. Closures will last several months. Some traffic diversion onto alternate routes<br>Bicycle – medium impact on intersecting and parallel bike routes | Sidewalk – low to high impact along the Corridor<br>Road – medium impact along the Corridor<br>Bicycle – low to medium impact along the Corridor<br>For all of the above, the greatest impact would occur where the tunnel boring machine is launched and stored, and at station and ventilation system areas |

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| | ii. Impact on parking | High impact along the Corridor (however, parking would be reduced during service operation anyways) | Medium impact on 10th Ave. and intersecting north-south routes |
| | iii. Impact on local businesses | Medium to high impact on street businesses for several months per block. However, access will be retained at all times | Low to high impact on street businesses at stations and ventilation system locations for several months |
| | *iv. Impact on existing utility systems* | *Medium impact along the Corridor* | *Low to medium impact, with greatest impact at stations and ventilation system areas* |
| **d. Duration of Construction** | i. Duration of construction for entire project | 3 years | 4 years |
| **e. Contribution to the Pedestrian and Bicycle Environment *and to Community Cohesion**** | i. Width and condition of sidewalks | Width of sidewalks reduced at stations | Sidewalk space increased at stations |
| | *ii. Potential to include public art* | *High potential at stations and along guideway* | *High potential at stations* |
| | *iii. Emphasis of the human scale* | *Strong emphasis on human scale* | *Low to medium emphasis on human scale* |
| | *iv. Overall attractiveness of the public realm* | *Significant improvement to public realm, due to: a reduction of through traffic, an increase of plants and other types of materials, and the possibility of integrating public realm design guidelines in the zoning of properties around the station areas* | *Little positive effect on public realm, due to: less reduction of through traffic, and little opportunity to add more landscaping and other types of materials. However, it may be possible to integrate public realm design guidelines in the zoning of properties around the station areas* |
| | *v. Presence of mixed land use* | *Level of mixed- use development increased at station areas and along the Corridor* | |
| | *vi. Presence of cycling infrastructure* | *Bicycles allowed on trains and bike storage available at stations and along Broadway. No additional bike lanes are added to Broadway.* | |
| | vii. Effects on existing bike traffic | Increased possibility of auto/bike/bus conflicts at station areas. Where LRT crosses bikeways, intersections will be treated to minimize bike/train conflicts | Little effect on existing bike traffic |
| ***f. Impact on First Nations*** | *i. Impacts to First Nations' lands* | *No impact to First Nations' lands* | |

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| | *ii. Ability to meet First Nations' community goals* | *No impact to First Nations' community goals* | |
| **g. Cultural/ Heritage Impacts** | i. Impacts to heritage properties/buildings/sites | No impact | Low to medium impact – potential ground settlement risk on 10th Ave. Heritage trees may also be removed at station areas. |
| | ii. Impacts to culturally significant properties/buildings/sites | No impact | Low to medium impact – potential ground settlement risk on 10th Ave. |
| ***h. Practicality and Public Acceptability*** | *i. The feasibility and anticipated public support of the proposed system* | *Businesses may be concerned about the loss of customer parking and the several months of construction disruption. However, the system may be easier to fund* | *Merchants may be concerned that the negative impacts of the Canada Line will also occur along the Corridor. The cost of the system may also pose funding challenges* |

### *a. Consistency with UBC's plans and policies*

Indicator i: Ability to meet UBC's academic, community, and research targets and goals

*Data sources*

- UBC's goals and targets from various planning documents, including UBC's *Official Community Plan* (Metro Vancouver, 1997), *Comprehensive Community Plan* (UBC, 2000), *Main Campus Plan* (UBC, 1992), *Strategic Transportation Plan* (UBC, 2005), *University Boulevard Neighbourhood Plan* (UBC, 2003), and draft *UBC Vancouver Public Realm Plan* (UBC Office of Architect, 2008).

*Approach*

- Assess whether the LRT and SkyTrain options will meet the goals and targets stated in the above planning documents.

*Results*

Both options will strongly support UBC's on-going and future academic, community, and research work.

### b. *Ability to Generate Positive Land Use Changes*

Indicator i: Ability to attract desired development, reduce commercial turnover, and support existing development

Indicator iii: Ability to achieve the minimum rapid transit-supportive density requirements in 2021

*Data Sources*

- Previous documentation of the LRT and SkyTrain's ability to attract desired development, reduce commercial turnover, and support existing development, from the 1999 *Beyond the B-Line* study.
- 2008 zoning for the study areas, from the City of Vancouver (2008a).
- *EcoDensity Charter* and its associated policies, from the City of Vancouver (2009c).
- City of Vancouver's *Zoning and Development By-Law* (City of Vancouver, 2009d).
- Minimum recommended density for LRT and SkyTrain, from Litman (2009a) and Pushkarev and Zupan (1977).
- Recommended buffer distance from transit stations (500 m or a five- to six- minute walk) where transit-supportive densities should be encouraged, from the City of Calgary's *Transit-Oriented Development: Best Practices Handbook* (2004).
- 2006 residential and employment population per census tract, from Statistics Canada (2008 and 2009).

*Approach*

- To evaluate the ability of the two systems to attract desired development, reduce commercial turnover, and support existing development, the results of the 1999 study were taken into account, along with the following: the developments that have occurred since 1999; the current zoning; the *EcoDensity Charter* and its associated policies; and the City of Vancouver's *Zoning and Development By-Law*.
- Determine the study areas by defining a circular buffer zone with a 500 m radius around each station. The northern and southern boundaries of these study areas are approximately 5 blocks north and south of Broadway. UBC is excluded as a study area as it is a well-known major destination.
- Calculate the average gross residential and employment density of each buffer zone by dividing the total population of the census tracts that lie within the buffer zone by the total area of these census tracts.
- Apply the following annual growth rates for residential and employment density, assuming that not all of the growth predicted for the surrounding neighbourhoods will be in the study areas due to a decreasing availability of developable land.
    - For all study areas east of Vine St. (including the study area for the Arbutus station), with the exception of the Great Northern Way Campus station: the annual residential and employment density will grow by 0.9% between 2009 and 2014; after that, in anticipation of the UBC Line being built, development will gradually increase, reaching a growth rate of 2% in 2021.

- For the Great Northern Way Campus station: the annual residential and employment density will grow by 0.9% between 2009 and 2014; after that, due to significant campus developments being built, the employment population will increase substantially and the population density will rise steadily, reaching an annual growth rate of 4% in 2021.
- For study areas west of Vine St.: the annual residential and employment density will grow by 0.3% between 2009 and 2014; after that, development will increase slightly, reaching a growth rate of 0.6% in 2021.

- Assume that light rail requires a combined residential and employment density of at least 49 persons per hectare to support the system, and assume that SkyTrain requires at least 66 persons per hectare.
- Compare the 2021 residential and employment densities to the recommended minimum average densities for LRT and SkyTrain.

*Results*

**Figure 4-12: Transit village in Central Platte Valley, Denver, CO.** Source: Utter (2008).

Both the LRT and SkyTrain will provide an opportunity to help attract new small and large commercial and residential projects and serve the existing local employment centres. This is attributed to the crucial role the Corridor already plays in the region in terms of employment, commercial activity, and residential development. In addition, the proximity to compatible land uses and intense developments such as the new Olympic Village, and the Canada Line station and commercial hub at Cambie St. and Broadway further enhance Broadway's central role. Both options will also support the area's existing land use plans and zoning.

Much of the study areas are zoned as mixed use commercial and residential districts or multi-family dwelling districts (see Table A-10). As a result, assuming that the *EcoDensity Charter* and its associated policies will promote infill development in the study areas and developers will take advantage of the density-bonusing program (where developers are able to build to a higher density in exchange for the provision of certain amenities or services requested by the City), the density of most of the study areas will grow. It is therefore concluded that all of the study areas will be able to attract densities that are supportive of light rail (i.e., the densities are at least 49 persons/ha) and that the development of transit villages around the stations will be possible (an example is shown in Figure 4-12).

In the case of the SkyTrain option, 8 out of the 10 study areas will be able to meet the density threshold recommended for rapid transit (66 persons/ha). The development of transit villages will also be possible. The areas where current zoning is not supportive of SkyTrain are west of Vine St., where the zoning is primarily single-family dwellings. Consequently, the densities in these areas will not likely have increased much by 2021 and the densities around the Alma and Sasamat stations will be below 66 persons/ha.

See Appendix C for the sensitivity test that illustrates how the systems' ability to achieve the minimum density requirements would be affected by changes to the study areas' population growth rates.

*Data Gaps and Challenges*

To calculate the population densities more accurately, residential and employment data should be collected at the block level. Currently, the smallest scale at which employment population data is collected is by dissemination area, and even this information is only available at a cost and with the use of GIS. The information for residential density is available at the block level. However, it is again not readily available (the data needs to be purchased from Statistics Canada and the use of GIS is necessary).

### *c. Effects of Construction on Community*

Indicator i: Extent of sidewalk, road, and bicycle lane closures, and impact on vehicular traffic (along the Corridor, intersecting north-south routes, and alternate routes where traffic may be diverted)
Indicator ii: Impact on parking
Indicator iii: Impact on local businesses
Indicator iv: Impact on existing utility systems

*Data Sources*

- Previous impacts on sidewalk, road, and bicycle lanes and on traffic, parking, and businesses, documented in the 1999 *Beyond the B-Line* study.
- Conceptual design of the LRT and SkyTrain systems.
- Location of utility systems along the Corridor from the City of Vancouver's VanMap program (2008b).
- Construction information for the Canada Line, from the Canada Line website (InTransitBC, 2009).

*Approach*

- Using the information described above, rate each alternative using a high-medium-low scale in terms of its impact on sidewalks, road, and bicycle lanes during the construction phase. The same information is used to evaluate each option's impact on local businesses and existing utility systems. Assumptions are made with regards to the construction staging process.

*Results*

**Figure 4-13: Construction of the streetcar tracks in Portland, OR.** Source: APTA (2008).

The track work required for the LRT option (see Figure 4-13) is expected to have a medium to high impact on sidewalks along the Corridor. Most of the closures will occur at station areas where sidewalks need to be altered. The impact on the road will be medium to high, with the greatest impact at intersections. There will be road closures along either direction of the Corridor, resulting in traffic diversions onto alternate routes and loss of parking along the Corridor. There will likely be traffic delays along the intersecting north-south routes; at minor intersections, there may be partial to complete closures, depending on further evaluations. There will also be some negative impact on local businesses as the tracks are installed and stations are built. The construction, however, will be phased so that the road closures will only be in place for several months (the 1999 study estimated six months per block). As well, a minimum of one lane per direction of traffic will be maintained along Broadway at all times. With regards to bicycle lanes, there will be a medium impact as Broadway is not a dedicated bicycle route. There may, however, be an impact on cyclists wishing to get to destinations along the Corridor. Intersecting bicycle routes, however, may be affected and there may be diverted traffic on parallel bike routes.


**Figure 4-14: Road and sidewalks impacts during construction of the Canada Line in Downtown Vancouver.**
Source: InTransitBC (2009).

The SkyTrain option will have a diverse range of impacts on sidewalks (from low to high, depending on the location); the impacts will be particularly high at points where the tunnel boring machine is launched and stored, at station areas, and where the construction of the ventilation systems involves surface work. As a result, there will be reduced business and pedestrian access. There will also be a medium impact on roads, most of which will again occur at station areas, ventilation system areas, and where the tunnel boring machine is launched and stored. This will involve: traffic closures along 10th Ave. and intersecting north-south routes; traffic diversions onto alternate routes; and a loss of parking along 10th Ave. and some sections of overlapping north-south routes. As for bicycle lanes, the impact will be low except at station areas, points where the tunnel boring machine is launched and stored, and ventilation system construction areas. There will also be a negative impact on local businesses for several months as the stations and ventilation systems are being built.

Lastly, the LRT alternative will involve the relocation of utilities underneath the inner lanes of the Corridor. Therefore, light rail is considered as having a medium impact on utilities. The SkyTrain alternative, on the other hand, will only require the relocation of utilities at stations and ventilation system areas. It is therefore considered as having a low to medium impact on utilities.

See Appendix C for the sensitivity analysis that examines how changing the construction method for the SkyTrain alternative would impact the community during the construction period.

### *d. Duration of Construction*

Indicator i: Duration of construction for Entire Project

*Data Sources* and *Approach*

- Adopt the previous values quoted in the 1999 *Beyond the B-Line* report.

*Results*

The LRT system will take 3 years to be constructed and the SkyTrain will take 4 years to be constructed.

### e. *Contribution to the Pedestrian and Bicycle Environment and to Community Cohesion*

Indicator i: Width and condition of sidewalks
Indicator ii: Potential to include public art
Indicator iii: Emphasis on the human scale
Indicator iv: Overall attractiveness of the public realm
Indicator v: Presence of mixed land use
Indicator vi: Presence of cycling infrastructure
Indicator vii: Effect on existing bike traffic

*Data Sources and Approach*

- Previous documented effects on pedestrian and bicycle environment, from the 1999 *Beyond the B-Line* report.
- Pedestrian and bicycle environment effects documented for other rapid transit systems such as the Portland streetcar, from Condon et al. (2008).
- Using the information described above, evaluate each alternative's effect on indicators i to vii.


**Figure 4-15: Streetscape improvements from sidewalk reconstruction enhancing the pedestrian and cycling environment.** Source: Utter (2008).

*Results*

If the LRT alternative is selected, the sidewalk at some stations will be reduced to make room for station platforms. As the 1999 *Beyond the B-Line* study indicated, however, setbacks for new buildings could be required and additional right-of-way could be acquired. Indeed, as of 2003, new buildings within the commercial zoning C2 have had to include a set back of at least 2' from the property line. Presently the Vancouver city council is also considering making the same amendment for C-2C districts, which are located along Broadway (City of Vancouver, 2009a).

There will also be a high potential to include public art, as art displays can be installed at the stations, and along the guideway. In addition, as the sidewalk and streetscape is being reconstructed, new sidewalks, lamp posts, recycling and garbage receptacles, and other street furniture that emphasize the human scale may be provided (see Figure 4-15). As well, the size of the LRT stations, the public art pieces, and the height of the light rail vehicles will emphasize the human scale all along the Corridor.

As for the overall attractiveness of the public realm, the reduction of through traffic will increase pedestrian’s sense of safety. Additionally, removing on-street parking will provide an opportunity to introduce landscaping as a greener and more attractive buffer to protect pedestrians from vehicular traffic (pedestrian and train conflicts would be minimized through various countermeasures such as automatic pedestrian gates, signals, signage, etc). The plant material, as well as the stations themselves, will also offer more opportunities to use a larger variety of materials within the public space (e.g., natural stone pavers for the station platforms, wood composite seats, etc.). Furthermore, as the LRT is being constructed, there may be the possibility of integrating certain public realm design guidelines in the current zoning of properties around the station areas. This will ensure new developments also positively contribute to the public realm. Collectively, these improvements will enhance the public realm and make the area even more walkable than it currently is (the Corridor already follows a grid-like street pattern, which improves route directness). In turn, this will facilitate more interactions between community members and promote community cohesion. In addition, increased transit use and the high visibility of the LRT system will promote commercial activity (e.g., small retail) at station areas as well as all along the Corridor, adding yet more mix and diversity to the urban landscape.

In terms of the bike environment, bike lanes will not be implemented along Broadway. The narrowed travel lanes at station areas will also increase the chances of auto/bus/bike conflicts for those cyclists traveling along Broadway. For those who are travelling along north-south intersecting bikeways, however, LRT crossing countermeasures (e.g., signage, automatic gates, traffic and pedestrian signals, etc.) will be implemented to minimize bike/train conflicts. In addition, bike racks inside the vehicles and bike racks at the stations will promote cycling.

**Figure 4-16: A drawing of the Canada Line station access point in Yaletown, Vancouver.**
Source: InTransitBC (2009).

If the SkyTrain alternative is selected, sidewalks will likely be increased at surface access points (see Figure 4-16 for an example). As well, there will be a high potential to include public art at the stations. However, the minimal streetscape improvements and the underground stations with high ceilings will place less emphasis on the human scale. There will also be minor landscaping added and the SkyTrain station access points will not offer many opportunities to incorporate different materials at the street level. There may, however, be an opportunity to incorporate public realm design guidelines into the current zoning of properties around the stations. In addition, while the retention of parking along the curb lanes will retain a buffer between pedestrians and vehicular traffic, this buffer will not be as visually appealing as landscaping. Therefore, overall the public realm will not be as attractive as the LRT option; as a result, the physical environment will play less of a role in facilitating positive interactions between community members. Nonetheless, increased transit use and commercial activity at station areas and along the Corridor will increase the level of mixed-use development and therefore the amount of pedestrian activity along Broadway.

Finally, similar to the LRT system, bike lanes will not be implemented along Broadway. However, the current travel lane widths of Broadway will be retained; as a result, the risk of auto/bike/bus conflicts will not increase. Bikes will also be allowed inside the SkyTrain vehicles and bike racks will be available at stations.

### *f. Impact on First Nations*

Indicator i: Impacts on First Nations' lands
Indicator ii: Ability to meet First Nations' community goals

*Data Sources and Approach*

- Information on the location of First Nation communities, from the BC Ministry of Aboriginal Relations and Reconciliation website (2009).
- Information on the traditional territory of the Musqueam First Nation, from the Musqueam website (2009).

*Results*

Neither the LRT nor SkyTrain option would impact First Nation lands or their community goals, as the Corridor is not situated in areas that are subject to land claims.

### g. *Cultural/Heritage Impacts*

Indicator i: Impacts to heritage properties/buildings/sites
Indicator ii: Impacts to culturally significant properties/buildings/sites

*Data Sources*

- Previously documented impacts on culturally significant and heritage properties/buildings/sites, from the 1999 *Beyond the B-Line* study.
- Physical observation of the Corridor.

*Approach*

- Using the information described above, evaluate each alternative in terms of its impact on culturally significant and heritage properties/buildings/sites.

*Results*

The LRT option will not affect any culturally significant or heritage properties/buildings/sites, as the construction will take place in the median lanes, where there are no trees or buildings. Meanwhile, in the case of the SkyTrain option, there may be a potential ground settlement risk on $10^{th}$ Ave. due to the tunneling process. As the 1999 study indicated, the actual risks to heritage structures or trees is dependent on geological conditions, which would need to be investigated through geo-technical studies. As well, some of the heritage trees on $10^{th}$ Ave. may need to be removed at station areas.

### h. *Practicality and Public Acceptability*

Indicator i: Feasibility and anticipated public support of the proposed system

*Data Sources and Approach*

- Previous assessment of the effect on the business climate, as documented in the 1999 *Beyond the B-Line* study.
- The impact the Canada Line has had on local businesses from various editorial, newspaper, and online articles (Bermingham, 2009, Cernetig, 2009, C. Smith, 2009a, and C. Smith, 2009b).
- Using the above information, assess the feasibility of the LRT and SkyTrain systems, and the likelihood that the public will support these options.

*Results*

Once the LRT is built, increased ridership will contribute to a healthy retail and business climate along the Corridor, especially near the stations. Yet merchants will likely be concerned about the loss of parking at the stations and other segments of Broadway, fearing that this will detract customers from visiting their stores. They may also be concerned about the negative impacts of construction. However, the construction along each block will likely only last several months.

Given the recent negative experience that business owners along the Cambie Corridor have had with the Canada Line (Bermingham, 2009, Cernetig, 2009, C. Smith, 2009a, and C. Smith, 2009b), public support for another underground rapid transit system may be low. In the case of the Canada Line, it was originally planned that the bored tunneling method would be used for the entire underground section. A decision, however, was later made to switch to the more disruptive cut-and-cover method to reduce costs (*Ibid*). It has also been reported that merchants were originally told the open trench construction would only last three months when it actually took much longer (*Ibid*). Furthermore, considering the crisis that economies across the world are currently facing and the large deficits that governments are incurring, a costlier system such as the SkyTrain may encounter more funding challenges. As the funding sources have yet to be identified for the UBC Line, this may be a major barrier to extending the SkyTrain system.

### 4.2.4 Environmental Account

Table 4-5 provides a summary of the evaluation results for the environmental account.

**Table 4-5: Evaluation results for the environmental account**

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| **a. Impacts on Biodiversity** | i. Impact to wildlife | Low impact | |
| | ii. Impact to plant life | Low to medium impact | |
| | iii. Impact to green space | Green space could be added between the tracks | No impact to green space |
| **b. Impacts on Hydrology and Aquatic Habitats*** | i. Storm and ground water pollution during construction | Some run-off from construction equipment, which could be mitigated. | |
| | ii. Reduction of storm and ground water pollution during service life | Significant reduction in storm and ground water pollution | Some reduction in storm and ground water pollution |
| | iii. Construction impacts on ground, storm, and surface water quantity and flow | Little to no impact | Low impact |
| ***c. Air Pollutants Generated from Construction*** | *i. NOx emissions (tonnes)* | *10 tonnes from concrete production, with additional emissions from the use of motorized construction equipment* | *245 tonnes from concrete production, with additional emissions from the use of motorized construction equipment* |

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| | *ii. SOx emissions (tonnes)* | *Emissions from the use of motorized construction equipment* | *Significantly more emissions from the use of motorized construction equipment than LRT option* |
| | *iii. PM10 emissions (tonnes)* | *1 tonne from concrete production, with additional emissions from the use of motorized construction equipment* | *33 tonnes from concrete production, with additional emissions from the use of motorized construction equipment* |
| | *iv. Greenhouse gas emissions ($CO_2$) (tonnes)* | *3,400 tonnes from concrete production, with additional emissions from the use of motorized construction equipment* | *81,710 tonnes from concrete production, with additional emissions from the use of motorized construction equipment* |
| ***d. Resources Consumed for Concrete Production*** | *i. Volume of limestone and shale consumed (tonnes)* | *6,800* | *163,420* |
| | *ii. Volume of sand and gravel consumed (tonnes)* | *22,020* | *529,540* |
| | *iii. Volume of water consumed (tonnes)* | *2,210* | *53,210* |
| ***e. Preservation of Agricultural Lands*** | *i. Area of agricultural lands affected* | *No impact on agricultural lands* | |

### *a. Impacts on Biodiversity*

<u>Indicator i</u>: Impact to wildlife
<u>Indicator ii</u>: Impact to plant life
<u>Indicator iii</u>: Impact to green space

*Data Sources and Approach*

- Impacts to wildlife, plant, and green space based on physical observations of the Corridor.
- Experiences from the light rail systems in Western Europe and Victoria, Australia.
- Rate each option using a high-medium-low scale in terms of its impact to wildlife and plant life along the surface of the Corridor.
- Assess each option's potential to reduce or add green space along the Corridor.

*Results*

As Broadway is a built-up urban neighbourhood with few natural features (except for trees) and no critical wildlife habitats, both the LRT and SkyTrain options will have a low impact on wildlife. However, trees at LRT station areas may need to be relocated or replaced with other landscaping plants when the sidewalk widths are being reduced. Similarly, in the SkyTrain option, trees will need to be removed to make way for the station boxes.

Currently, there are no green spaces along Broadway. Therefore, there will be no effect on green space if the SkyTrain system is built. If, however, the LRT system is built, grass or biofilters could be placed between the tracks, thereby increasing the amount of green space along Broadway. Examples of such a design can found in the light rail systems in Bordeaux, Barcelona, Czech Republic, Frankfurt, St-Etienne (see Figure 4-17), and Strasbourg, who use grass to incorporate landscaping with good urban design (Bottoms, 2003 and Meinhold, 2009). The Coast to Coast light rail system in Victoria, Australia is also considering installing biofilter trenches in between the tracks to filter stormwater (City of West Torrens, 2009). The UBC Line light rail system could consider adopting one of these designs.

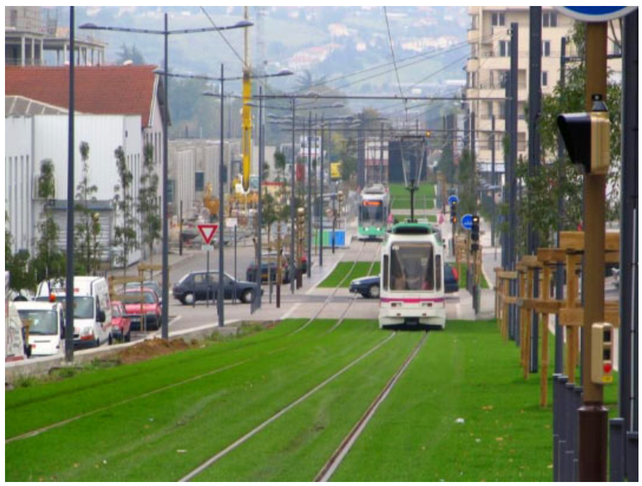

**Figure 4-17: Green light railway in St. Etienne, France.** Source: Meinhold (2009).

### *b. Impacts on Hydrology and Aquatic Habitats*

Indicator i: Storm and ground water pollution during construction
Indicator ii: Reduction of storm and ground water pollution during service life
Indicator iii: Construction impacts on ground, storm, and surface water quantity and flow

*Data Sources and Approach*

- Using the experience from other similar construction projects, assess each option's potential to generate storm and ground water pollution during construction and service life and its impact to water quantity and flow during construction.

*Results*

In both the LRT and SkyTrain options, there will likely be some pollution run-off generated by construction equipment. However, this pollution could be reduced with mitigation measures.

The LRT system will reduce road capacity, and as a result there will be less rubber-tired vehicle traffic along the Corridor. While some of this traffic may be diverted onto alternate routes, the overall number of vehicles on the road and vehicle-kilometres driven will likely be reduced. Some of the passenger vehicle trips will be replaced by public transit trips as well as walking and cycling trips, as the pedestrian and bicycle environment will be significantly enhanced. Furthermore, the installation of biofilters between the tracks will also help treat some of the storm water. Consequently, storm and ground water pollution from road traffic will be diminished. On the other hand, during the operation of the SkyTrain line, there will be no reduction in road capacity and no biofilters installed. The pedestrian and bicycle environment will also be less attractive than the LRT scenario. Therefore, even though some Broadway users will shift from passenger vehicles to public transit, walking, and cycling, storm and ground water pollution will not be reduced to the same extent.

As the LRT line is being constructed, there will be very little to no impact to water quantity and flow. On the other hand, as the SkyTrain line is being constructed, there will be some (although not very significant) impact to the ground water, as the excavated soil will need to be dewatered before it is removed. As a result, some of the area's ground water of the area will be diverted into the storm water system. As there are no surface waters along the Corridor, there is little risk of impacting fish habitat.

### *c. Air Pollutants Generated from Construction*

Indicator i: NOx emissions (tonnes)
Indicator ii: SOx emissions (tonnes)
Indicator iii: PM10 emissions (tonnes)
Indicator iv: Greenhouse gas emissions ($CO_2$) (tonnes)

*Data Sources and Approach*

- See Appendix B for the comprehensive list of data sources and steps followed to calculate the volume of concrete that will be used to construct the guideway and stations of the LRT and SkyTrain systems, and the emissions that will be generated from concrete production.

*Results*

Due to the production of concrete, the LRT option will generate approximately 10 tonnes of nitrogen oxides (NOx), 1 tonne of respirable particulate matter (PM10), and 3,400 tonnes of greenhouse gases (measured in carbon dioxide equivalents). The construction of the SkyTrain option will generate approximately 245 tonnes of NOx, 33 tonnes of PM10, and 81,710 tonnes of greenhouse gases.

See Appendix C for the sensitivity analysis that examines how changing the construction method for the SkyTrain alternative would impact the emissions generated during the construction period.

*Data Gaps and Challenges*

No information sources could be found to estimate the amount of fossil fuels and types of construction equipment that would be used to construct the LRT or SkyTrain line. Despite this, Appendix B has provided an explanation of how emissions from the use of motorized construction equipment could be calculated.

### d. *Resources Consumed for Concrete Consumption*

Indicator i: Volume of limestone and shale consumed (tonnes)
Indicator ii: Volume of sand and gravel consumed (tonnes)
Indicator iii: Volume of water consumed (tonnes)

*Data Sources*

- Concrete quantities for Portland Transit Mall line segment, from TriMet (2009a).
- Concrete quantities for Canada Line, from IBI Group (2009).
- Emission factors and resource consumption rates for cement, from EcoSmart Concrete (2009).
- See Appendix B for a more comprehensive list of data sources.

*Approach*

- Calculate the volume of concrete used per station component and per kilometre of guideway and convert it to a weight measurement, assuming that the density of concrete is 2,242 kg/$m^3$.
- Calculate the amount of cement, water, sand, and gravel used to produce each tonne of concrete.
- To determine the emissions released and resources consumed, multiply the emission factors and resource consumption rates by the amount of cement and concrete used.
- See Appendix B for more details on the methodology used.

*Results*

For the LRT option, an estimated 6,800 tonnes of limestone and shale will be used to make cement, one of the components of concrete. Other resources that will be used in the production of concrete are 22,020 tonnes of sand and gravel and 2,210 tonnes of water. In the case of the SkyTrain option, approximately 163,420 tonnes of limestone and shale, 529,540 tonnes of sand and gravel, and 53,210 tonnes of water will be used for the same purposes (Figure 4-18 shows the concrete structures that were built for the Downtown underground section of the Canada Line).

See Appendix C for the sensitivity analysis that examines how changing the construction method for the SkyTrain line would affect the volume of concrete used, as well as the environmental footprint of the system.

**Figure 4-18: Photo showing construction of the Canada Line in Downtown Vancouver and the concrete used in the system.** Source: InTransitBC (2009).

### *e. Area of Agricultural Lands Affected*

Indicator i: Impact on agricultural lands

*Data Sources and Approach*

- Location of agricultural lands and community gardens, from VanMap (City of Vancouver, 2008b).
- Rate each option's impact on the preservation of agricultural lands using a high-medium-low scale.

*Results*

Currently, there are no large-scale agricultural lands along the Corridor. There is a community garden located on the southwest corner of Broadway and Clark St.; however, neither system would impact this garden, as it not located within the LRT or SkyTrain rights-of-way.

### 4.2.5 System Operation Account

Table 4-6 provides a summary of the evaluation results for the system operation account.

**Table 4-6: Evaluation results for the system operation account**

| Evaluation Criteria | Key Indicators | Light Rail Transit | SkyTrain |
|---|---|---|---|
| **a. System Flexibility, Reliability, Expandability, and Durability** | i. Ability to integrate with a future north-south transit line | Relatively easy | More difficult |
| | ii. Ability to expand the system to meet future demand | Relatively easy | More difficult |
| | iii. *Ability to gain operational efficiencies with the initial introduction of the UBC Line* | *Relatively little opportunity to gain efficiency* | *Significant opportunity to gain operational efficiencies, as the existing SkyTrain fleet, maintenance facilities, and other infrastructure will be utilized for the UBC Line* |
| | iv. Ability to be respond quickly to vehicle problems and restore service | Shorter response times | Longer response times |
| | *v. Travel time variability* | *Low to Medium* | *Low* |

### *a.* System Flexibility, Reliability, and Expandability, and Durability

Indicator i: Ability to integrate with a future north-south transit line
Indicator ii: Ability to expand the system to meet future demand
Indicator iii: Ability to gain operational efficiencies with the initial introduction of the UBC Line
Indicator iv: Ability to be respond quickly to vehicle problems and restore service
Indicator v: Travel time variability

*Data Sources and Approach*

- Information regarding a possible north-south streetcar route in the future, from the City of Vancouver's policy report, *Vancouver Transit Strategy* (2002).
- Assess each option's ability to integrate with a future streetcar north-south line, expand to meet future demand, increase operation efficiency, and respond to emergencies.
- Assess the likelihood of there being travel time variability, based on the designs of the systems.

*Results*

It will be easier to integrate a north-south streetcar line with an LRT line than with a SkyTrain line, as both the LRT and streetcar infrastructure will be at-grade. Similarly, it will be easier to expand the LRT system than the SkyTrain system as the latter involves an intensity of infrastructure that is less easily scalable in terms of cost and the physical infrastructure involved. There will, however, be little operation efficiencies gained with the initial introduction of the LRT line, as a whole new system will need to be built (new vehicles, new maintenance facilities, etc.). On the other hand, the SkyTrain line would be able to use the existing SkyTrain fleet, maintenance facilities, and other existing infrastructure.

It is anticipated that light rail vehicle drivers will be able to respond to emergencies quicker. However, snow during the winter season may pose more problems to the tracks. In Portland, special pantograph heating elements are activated on all trains to keep the overhead wires clear of ice and snow, and plows are used to clear packed snow out of the track grooves (TriMet, 2009b). For more serious weather events, however, workers have to go out and clear problem areas manually (*Ibid*). Meanwhile, it may take technicians and response staff longer to reach problem SkyTrain vehicles. However, snow may pose less of a problem to operations.

Lastly, as the LRT system is at-grade, there may be some variability in the travel time of the trains. However, with traffic signal priority measures, this variability can be minimized. Meanwhile, the SkyTrain line will be completely isolated from vehicular traffic; therefore, the variability in travel time will be low.

## 4.3 Summary of Strengths of the LRT and SkyTrain Alternatives

As Table 4-7 indicates, both the LRT and SkyTrain alternatives have their relative strengths. The strengths of the LRT option lie mainly in its ability to support social and community objectives and reduce negative environmental impacts associated with transportation. It will contribute more to the pedestrian and cycling environment, reduce more storm and ground water pollution during its service life, require 96% less concrete to construct (which reduces air emissions and the amount of natural resources consumed), and make less of an impact on cultural/heritage sites. The stations will also be more accessible. Given the current zoning of the Corridor, the areas around the proposed stations will also be much more likely to reach densities that are supportive of LRT than SkyTrain. Furthermore, an LRT line will be significantly more cost-effective to build (the capital cost will be 64-80% less than the SkyTrain option) and it will offer more flexibility to expand and integrate with future transit systems. In addition, it will require less funding for the provision of traffic services (5% less) and result in lower congestion costs (27% less). Lastly, an LRT system may be more practical to build and may receive more public support.

On the other hand, the SkyTrain option offers a lower annual operating cost (59% less) and more parking revenue to be collected by the City of Vancouver and TransLink. It will also attract 10% more ridership, thus generating 10% more in gross annual operating revenue. Additionally, if the system is built using the bored tunneling technique, there will be less of an impact on the community during the construction period. There will also be operation efficiencies gained when the new Skytrain line is introduced. Finally, as the SkyTrain will be operating completely in an exclusive right-of-way, there will be less variation in travel time. Passengers can therefore be more confident in the accuracy of the official operating schedule.

**Table 4-7: Summary of the key strengths of the LRT and SkyTrain options in relation to each other**

| | LRT | SkyTrain |
|---|---|---|
| **Financial** | • Lower total capital cost (64-80% less)<br>• Lower capital cost per passenger kilometre (54% less)<br>• Lower capital cost per new passenger (58-77% less)<br>• Lower cost of traffic services (5% less) | • Lower total annual operating cost and annual operating cost per service hour (59% and 61% less, respectively)<br>• Lower annual operating cost per rider and per new passenger (62% and 65% less, respectively)<br>• Higher gross operating revenue (10% more)<br>• More parking revenue (actual percentage depends on the number of stalls removed in the LRT option) |
| **Customer Service** | • Higher net reduction in congestion cost (27% more in reduction of congestion cost)<br>• Stations are more accessible as platforms are at-grade | • More total boardings in 2021 (10% more)<br>• More new boardings in 2021 relative to base case (23% more) |
| **Social and Community** | • Higher likelihood of achieving the minimum transit-supportive density in all study areas<br>• Shorter construction period<br>• Larger contribution to pedestrian and cycling environment and to community cohesion<br>• Less cultural/heritage impacts<br>• May be more practical and acceptable by the public | • Surrounding communities less affected by construction |
| **Environment** | • Higher reduction of storm and ground water pollution during service life<br>• Less air pollution and greenhouse gases released from concrete production (96% less) and from the operation of construction equipment<br>• Less water, limestone, shale, sand, and gravel consumed for concrete production (96% less) | |
| **System Operation** | • More compatible with a future north-south streetcar line<br>• More easily expanded to meet future transit needs<br>• Shorter response time to address vehicle problems and restore service | • Less travel time variation<br>• Operational efficiencies gained with the initial introduction of the UBC Line<br>• Less easily affected by snow and ice |

# 5. Discussion and Recommended Further Research

This chapter begins with a more detailed look at the value of including the new social and environmental criteria and indicators this study has added to the MAE framework. It then describes the challenges that have been encountered when attempting to measure these indicators. Recommendations are also made on how these challenges could be addressed in the future. Lastly, it ends by discussing areas requiring further research.

## 5.1 Value of the Newly Added Evaluation Indicators

The UBC Line case study has illustrated that many of the new economic, social, and environmental performance indicators included in the MAE framework cannot be easily quantified. Unlike indicators such as capital and operating costs, factors such as community cohesion and impact on First Nations cannot be readily expressed in dollar terms or other quantitative units. Nonetheless, this challenge should not deter us from taking them into consideration when conducting a full evaluation. Many past conventional economic evaluations conducted for large transportation projects have neglected these more-difficult-to-measure effects, labeling them as *intangibles* (Litman, 2009b). As a result, their significance has been underappreciated and poorly understood by decision-makers, and decisions are made based on easy-to-measure factors at the expense of more-difficult-to-measure factors (*Ibid*). In addition, the projects that are built (e.g., road expansion projects) have often led to unanticipated negative consequences, such as more congestion (e.g., by causing induced travel) and poorer air quality (Cervero, 2001). Such incomplete evaluations also run the risk of being ignored by decision-makers altogether. For example, if public acceptability or political feasibility is not included in an analysis, despite the fact that it is always at the forefront of politicians' minds, the evaluation may not be seen as realistic or practical, and therefore not useful.

Moreover, as the UBC Line case study has shown, there has been much research done in the recent decades to systematically measure these so-called *intangible* effects. This research has resulted in conversion factors (to measure effects such as traffic congestion and cost of traffic services) that can be used to yield monetary results. As shown by the sensitivity analysis in Appendix C, elasticity values have also been developed to explore how changing the price or characteristic of a particular good/service affects the consumption of it or another related good/service. As well, physical and qualitative indicators that are meaningful and measureable have been well developed and applied to projects worldwide.

## 5.2 Addressing the Challenges of Measuring the New Indicators

The UBC Line case study has also identified key data gaps that may pose a challenge to the full UBC Line MAE. These gaps appear to be relatively common, and likely exist in other systems. The lessons learned here could therefore be applied elsewhere. In the following section, these key data gaps are discussed, and the ways in which they could be addressed are explored.

Let us first examine the topic of ridership. TransLink currently determines transit ridership using boarding data. Thus each time a passenger transfers onto a different transit mode, their transfer is counted as another boarding. As explained by Richmond (2001), this type of unlinked data may inflate the actual number of transit trips made after a new system is built. Linked ridership, in comparison, measures the number of complete journeys made and provides a more realistic and accurate picture of how many new riders are actually using the system. Although TransLink does not currently collect linked ridership information, they do conduct trip diary surveys, where customers are asked to provide details of where and how they travel, and for what purpose. This information could be extrapolated to estimate how many linked trips are made between different locations. If feasible, an alternative and more accurate method would be to implement a smart card system and program it so that it tracks linked trips.

Continuing with the topic of ridership, this study has found that residential and employment population projections specific to the Corridor are also unavailable. Projections only exist at the traffic area zone level, which includes a much larger geographical area than the Corridor. To estimate linked/unlinked ridership for the future, such specific projections should be done. These projections may be done by the City of Vancouver in partnership with Metro Vancouver.

Data on the vehicle-kilometres currently traveled along the Corridor is also not readily available. The only organization that may have this data is the Insurance Corporation of BC (ICBC), which collects such data through their vehicle emission control AirCare program. This information, however, is not shared with the public or with the City of Vancouver. To overcome this, the City of Vancouver could collect their own data so that indicators such as congestion cost can be calculated more accurately.

As noted in Chapter 4, however, the conversion factors used to calculate congestion and traffic services costs should be tailored to each locality. The same is true for the elasticity values used to estimate the effect of increasing vehicle operating costs on ridership. In the UBC Line case study, this was difficult to do due to a lack of data and time constraints. As a result, generic conversion factors and elasticity values were used to produce rough estimates that are at least in the correct order of magnitude. In the full MAE, however, further work will need to be done to determine which local factors need to be taken into consideration.

Perhaps one of the major gaps revealed in this study is the failure of past projects to consider the emissions from construction and the issue of resource consumption. Although emissions may be abated after a new transit system comes into service, for the duration of several months to years, the local community will be exposed to harmful air pollutants (and greenhouse gas emissions) from the operation motorized construction equipment. Furthermore, in addition to the natural resources required to make construction materials, the construction materials themselves carry embodied energy (which is defined as the energy that is required to make a product). Adding to that, there could be negative environmental or social impacts associated with the production of the construction materials. To account for such impacts, project managers could be required to keep records of how much fuel and other resources are consumed by their projects. This data can then be used by future project evaluation studies to better predict such construction impacts. While these are still rough estimates, at least some general conclusions could be drawn from them.

Lastly, the UBC Line case study has demonstrated that like conventional indicators, many of the new effects are interconnected. The outcome of one indicator can have implications for several other factors. For example, the volume of concrete used for construction affects the amount of air pollutants produced as well as the amount of water, sand, gravel, limestone, and shale consumed. It has also shown that contributing factors can have complementary or contrasting effects on a particular indicator. For example, reducing the width of some of the sidewalks to build light rail stations may have a negative impact on the pedestrian environment, but adding landscaping and pedestrian furniture to reconstructed sidewalks would counteract this undesired impact. As a result, the final outcome of an indicator can be difficult to predict with a fair level of accuracy. Nonetheless, including such indicators into an evaluation will help better inform decision-makers. Care simply needs to be taken to clearly demonstrate the relationships and trade-offs and to ensure effects are not counted more than once.

## 5.3 Recommended Further Research

Aside from the research described in the above section, there are several other recommended areas that are worthy of further study. These suggestions are meant to help further improve the MAE framework and decision-making process for large-scale projects.

The first area of focus is the development of critical factors for the various indicators included in the new MAE framework. As described in the *Multiple Account Evaluation Guidelines,* a matrix of critical values would help decision-makers determine trade-offs in a more informed manner. Therefore, although the development of critical values was outside the scope of this case study, the inclusion of such values would be very valuable in the full UBC Line MAE. Research, however, will be required to determine how these values can be identified, as they have been excluded in the previous MAE projects reviewed by this study.

Secondly, this study has only included 2021 as the target year. As mentioned in Chapter 3, including another target year(s) further into the future (e.g., 2040) in the full UBC Line MAE would allow longer-term net benefits to be measured. Related to the topic of timing, discount factors should also be applied to determine how the value of the identified costs and benefits would change over time. For example, natural resources will likely become increasingly scarce and will therefore grow in value over time. Discount factors would help account for these trends. In addition, it is important to note that discount rates will likely fall over time. Recognizing this will mean that long term effects is given greater weight.

A third area of further research is examining the effects a new transit project has on the performance of the total system (e.g., total ridership and total revenues and expenditures). Extensive modeling work would need to be conducted to determine these system-wide effects.

Fourthly, more efforts should be placed on devising risk management strategies to address and minimize the risks identified by the sensitivity analysis. This work would strengthen an MAE and increase the likelihood a project will succeed. All too often these important steps are overlooked by transportation evaluation studies, which may be why so many projects end up with issues such as cost overruns. By doing a thorough job in this part of the evaluation, such pitfalls can be avoided.

Although it is not explored extensively in this study, public engagement should be pursued hand-in-hand as the MAE analysis is being conducted and after it is completed. A similar process to the Columbia Pike Initiative's public consultation program described in Section 2.7 could be followed. This will ensure the public is continually updated on the status of the evaluations and they are able to raise issues or effects that may have been overlooked by the team of analysts. Involving the public in the decision-making process will also help the decision-makers identify the most preferred and appropriate option. Public engagement should be done through various means such as workshops, open houses, public forums, and surveys. There will of course, be many mixed opinions and perhaps debates about the results of the MAE. Some of the issues raised may also prove to be insignificant. This debate, however, will ensure the analysis is indeed comprehensive and addresses the distributional effects of the different alternatives. Moreover, effective communication and outreach will increase the likelihood that the public will support the final selected technology and system design in the long term.

Last but not least, conducting post-evaluations of a large project such as the UBC Line is of utmost importance. These evaluations are the only formal way to inform planners and decision-makers if the results of an MAE are accurate. They may also act as a powerful tool to help refine evaluation techniques and improve the way in which subsequent MAEs are performed. Unfortunately, due to time and resource constraints, most transportation projects do not conduct full post-evaluations. The benefit of the MAE framework is that the same indicators could be used in post-evaluations; such an approach is recommended for the UBC Line as well as for future transportation projects. To ensure the post-evaluations are conducted, however, there needs to be an explicit statement of how and when these evaluations will be conducted and that there is adequate funding. It is therefore recommended that post-evaluations be included in the initial description of the project so that funding is allocated to it and there is a plan and schedule in place that describes how and when the post-evaluation will be carried out.

With that being said, it is recognized that conducting post-evaluations can be difficult, as many changes (e.g., the cost of construction, inflation, demographics, and land use patterns) can occur as a new system is being built and after it comes into operation. Thus, it is difficult to say with certainty what a system would have been like in the absence of the new service under study. In response to this, Richmond (2001) states that,

> "What one can do is to identify structural changes in systems that the new service brought about – changes in the efficiency of existing bus systems due to reconfiguration, for example – while linking changes in total system ridership and financial performance over time to the commencement of new service as reasonably as the evidence allows." (p.151).

The present study recommends following this advice when performing post-evaluations. To accomplish this, however, detailed and accurate records will need to be kept to ensure structural changes can be identified relatively easily. Moreover, these records need to be consistently kept, so that comparisons across different years can be made.

# 6. Conclusion and Next Steps

The results of the pilot evaluation of the UBC Line have shown that different rapid transit technologies have their different advantages. While it is too early to draw any firm conclusions about these two technologies, this pilot evaluation does suggest that the LRT will be less costly to build and will yield more net social and environmental benefits than the SkyTrain option. On the other hand, the SkyTrain alternative will be able to attract a higher ridership and will have lower operating cost than the LRT alternative.

As mentioned at the beginning of this report, however, the main purpose of this study was to illustrate how the economic, social, and environmental effects of different rapid transit technologies can be better assessed and incorporated into the decision-making process with a more comprehensive MAE framework. This study has successfully demonstrated that the new criteria and indicators can be relatively easy to incorporate into the MAE approach using a variety of evaluation approaches. In most cases, the data is available; where only rough estimates can be found, general conclusions can be drawn. In many instances, there are also conversion factors that can be used to represent the results in monetary terms. The end result is that decision-makers can be presented with a much more well-rounded and comprehensive picture of how different rapid transit technologies will affect the health of the natural environment, community, and economy. Presenting them with matrices as was done in this project also enables the technologies to be more easily compared. Such a comprehensive evaluation methodology is absolutely necessary, especially given the circumstances and state of our natural and built environments. Our populations are continuing to grow as well as age, and natural and financial resources are increasingly stretched to the limit. Issues of congestion, mobility, and accessibility also continue to plague our communities, as do water, air, and land pollution, and disappearing agricultural lands.

Although the MAE framework developed by this study has been tailored to the UBC Line, it is not only applicable to this one particular project. It can be modified and adopted by future transportation projects, especially those focused on rapid transit. While an MAE analysis alone will not provide the solution to a particular issue, it will help inform public policy debates and help decision-makers focus on the true benefits and costs of different alternatives. It will also make explicit the different effects felt by different parties. Additionally, applying such an approach to all future transportation projects will ensure a consistent and thorough decision-making process is followed each time.

As a next step, the Provincial Government of BC could update and modify the original *Multiple Account Evaluation Guidelines* to include the criteria and indicators this study has added to the MAE structure. Then, through legislation or a code of practice, they could require or encourage all future large-scale transportation projects (not just those funded by a Crown corporation) follow this framework. Such a process is required in the US for all projects requiring significant new funding, and the New Approach to Appraisal methodology is the cornerstone of UK's transport appraisal practice. British Columbia could apply the lessons learned from the US and UK to set up a similar process. Furthermore, all major transportation projects should be required to use the MAE approach to consider alternative technologies, not just the timing or the alignment of the project, as was done for the Canada Line. Going a step further, a nation-wide evaluation framework could be developed so that projects between different provinces and territories are evaluated in more or less the same manner. This would lead to more transparent decision-making processes and more efficient use of our limited financial and natural resources.

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# Appendix A – Literature Review Summary

A summary of the literature reviewed is presented in Table A-1. The studies that have followed the MAE approach are marked with an asterisk to show which indicators are typically left out of rapid transit MAE studies.

**Table A-1: Summary of literature reviewed**

| | Transportation Benefits and Costs | Relevant Literature |
|---|---|---|
| FINANCIAL | Capital cost | Crown Corporations Secretariat (1995)*<br>UMA et al. (1999)*<br>Greer (1999)<br>IBI Group (2001)*<br>Richmond (2001)<br>IBI Group (2004)*<br>WMATA (2005)<br>Litman (2008a, 2008b, and 2009)<br>UK DfT (2009) |
| | Operating cost and cost-effectiveness | Crown Corporations Secretariat (1995)*<br>UMA et al. (1999)*<br>Richmond (2001)<br>IBI Group (2001 and 2004)*<br>WMATA (2005)<br>UK DfT (2009) |
| | Operating revenues | Crown Corporations Secretariat (1995)*<br>IBI Group (2001 and 2004)*<br>UK DfT (2009) |
| | Bus capital and operating savings, and other transportation infrastructure savings | IBI Group (2001)*<br>Richmond (2001)<br>UK DfT (2009) |
| | Cost of traffic services | Litman (2008a, 2008b, and 2009) |
| | Remaining or salvage value | Crown Corporations Secretariat (1993)*<br>IBI Group (2001)* |
| | Property values and land value-capture financing | Al-Mosaind et al. (1993)<br>McDonald (1995)<br>Gruen and Jeans (1998)<br>Cervero and Duncan (2000a and 2000b)<br>IBI Group (2001)* (only considers effects on property values)<br>Parsons Brinkerhoff (2001)<br>Smith and Gihring (2002)<br>Edge (2003)<br>Smith (2006)<br>Debrezion et al. (2007)<br>Doherty (n.d.)<br>UK DfT (2009) |

| | **Transportation Benefits and Costs** | **Relevant Literature** |
|---|---|---|
| | Benefits and costs of reduced parking | IBI Group (2001)*<br>Babalik-Sutcliffe (2002)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| CUSTOMER SERVICE | Ridership | Kain (1990)<br>Pickrell (1992)<br>Crown Corporations Secretariat (1995)*<br>UMA et al. (1999)*<br>Greer (1999)<br>Richmond (2001)<br>IBI Group (2001)*<br>Babalik-Sutcliffe (2002)<br>IBI Group (2004)*<br>Flyvberg et al. (2005)<br>WMATA (2005)<br>Litman (2009a) |
| | Connectivity (ease of transfers with other transportation modes) | Hass-Klaus and Crampton (1998)<br>UMA et al. (1999)*<br>Richmond (2001)<br>Babalik-Sutcliffe (2002)<br>DKS Associates (2006)<br>UK DfT (2009) |
| | Travel time savings | Crown Corporations Secretariat (1995)*<br>IBI Group (2001)*<br>Ben-Akiva and Morikawa (2002) (as it relates to user comfort)<br>IBI Group (2004)*<br>WMATA (2005)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) (including user comfort, journey quality, and quality of stations) |
| | Vehicle cost savings | IBI Group (2001)*<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Collision cost reductions | IBI Group (2001)*<br>Ben-Akiva and Morikawa (2002)<br>WMATA (2005)<br>DKS Associates (2006)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Effect of new transit projects on total system performance and affordability | Richmond (2001)<br>UK DfT (2009) |
| | Traffic congestion reduction benefits | Litman (2008a, 2008b, and 2009b) |

| | Transportation Benefits and Costs | Relevant Literature |
|---|---|---|
| | Station accessibility | UMA et al. (1999)*<br>IBI Group (2004)*<br>(however, neither study considers the presence of accessibility features at stations)<br>UK DfT (2009) |
| | Susceptibility to crime | Ben-Akiva and Morikawa (2002)<br>WMATA (2005)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Equity effects | Litman (2008a, 2008b, and 2009b) |
| | Effect on personal physical fitness | UK DfT (2009) |
| ECONOMIC DEVELOPMENT | Effect on tax revenue collected | IBI Group (2001 and 2004)*<br>UK DfT (2009) |
| SOCIAL AND COMMUNITY | Consistency with local, regional, and provincial goals and objectives | City of Vancouver (1997)<br>Metro Vancouver (1999)<br>UMA et al. (1999)* (did not include UBC's goals)<br>IBI Group (2001 and 2004)*<br>Metro Vancouver (2008)<br>Province of British Columbia (2008)<br>TransLink (2008)<br>UBC (1992, 2000, and 2005)<br>WMATA (2005)<br>UBC Office of Architect (2008)<br>UK DfT (2009) |
| | Ability to generate positive land use changes and ability to attract transit-oriented development | Knight and Trygg (1977)<br>UMA et al. (1999)* (only considers the ability generate positive land use changes)<br>Currie (2005)<br>Condon et al. (2008)<br>Condon and Dow (2008) |
| | Effects of construction on the community | UMA et al. (1999)*<br>IBI Group (2001)*<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Duration of construction | UMA et al. (1999)* |

| | Transportation Benefits and Costs | Relevant Literature |
|---|---|---|
| | Operational effects on vehicular traffic | Crown Corporations Secretariat (1995)*<br>UMA et al. (1999)*<br>Greer (1999)<br>IBI Group (2001 and 2004)*<br>WMATA (2005)<br>DKS Associates (2006)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Contribution to the pedestrian and bicycle environment and to community cohesion | UMA et al. (1999)* (only considers the width of sidewalks and effects on bike traffic in the final evaluation matrix)<br>IBI Group (2001)* (only includes certain effects)<br>IBI Group (2004)* (only considers community severance and certain visual effects)<br>WMATA (2005)<br>DKS Associates (2006)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Contribution to noise environments | Crown Corporations Secretariat (1995)*<br>UMA et al. (1999)*<br>IBI Group (2001 and 2004)*<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Cultural/heritage impacts | IBI Group (2001)*<br>DKS Associates (2006) (as it relates to urban identity)<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Practicality and public acceptability | UK DfT (2009) |
| ENVIRONMENT | Geotechnical conditions and construction-related issues | IBI Group (2001 and 2004)* |
| | Impacts on biodiversity | IBI Group (2001 and 2004)*<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Impacts on hydrology and aquatic habitats | Crown Corporations Secretariat (1995)*<br>IBI Group (2004)*<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Emissions of air pollutants generated from construction | Litman (2008a, 2008b, and 2009b) |
| | Air emissions reduced during operation | Crown Corporations Secretariat (1995)*<br>Greer (1999)<br>UMA et al. (1999)*<br>IBI Group (2001 and 2004)*<br>Litman (2008a, 2008b, and 2009b)<br>UK DfT (2009) |
| | Effect on mode split | UMA et al. (1999)* |

| | Transportation Benefits and Costs | Relevant Literature |
|---|---|---|
| | Impacts of resource consumption for construction purposes | Litman (2008a, 2008b, and 2009b) |
| SYSTEM OPERATION | System flexibility, reliability, and expandability, and durability | Crown Corporations Secretariat (1995)* (does not consider travel time variability)<br>UMA et al. (1999)* (does not consider travel time variability)<br>IBI Group (2004)* (does not consider travel time variability)<br>Ben-Akiva and Morikawa (2002)<br>Bruun (2005)<br>WMATA (2005)<br>UK DfT (2009) |

# Appendix B – Detailed Evaluation Methodology

### *Operating Cost Per Revenue Vehicle Hour for LRT*

Table B-1 provides a list of the light rail systems that were used to calculate average annual operating cost of an LRT system. The information is from the US Federal Transit Administration's National Transit Database (2008)

**Table B-1: 2007 operating cost (in $2009 CAD) for twenty-one light rail systems in the US**

| City, State | 2007 Operating Cost ($2009 CAD) |
|---|---|
| Portland, OR | $198 |
| Seattle, WA | $341 |
| Boston, MA | $242 |
| Newark, NJ | $389 |
| Philadelphia, PA | $159 |
| Baltimore, MD | $327 |
| Memphis, TN | $82 |
| Tampa, FL | $154 |
| Kenosha, WI | $131 |
| Cleveland, OH | $262 |
| Minneapolis, MN | $194 |
| Houston, TX | $272 |
| Galveston, TX | $125 |
| North Little Rock, AR | $69 |
| Dallas, TX | $377 |
| St. Louis, MO | $229 |
| Salt Lake City, UT | $124 |
| San Jose, CA | $318 |
| Sacramento, CA | $260 |
| San Diego, CA | $149 |
| Los Angeles, CA | $449 |
| **Average** | **$231** |

### *Vehicle Hours of Revenue Service for LRT and SkyTrain*

*Data Sources and Approach*

a. Calculate the number of weekdays, Saturdays, Sundays, and holidays in 2021 using a 2021 calendar.
b. Design an operating schedule for the LRT and SkyTrain using the current #99 B-Line (the B-Line) schedule as a basis.
c. For all the different times of day (e.g., peak period, midday, evening, etc.), calculate the number of trains that would pass a single point (e.g., Commercial Dr.) from both directions in an hour by using Equation B-1.

**Equation B-1: Number of trains passing a single point from both directions in one hour**

$$\frac{\text{60 minutes/hour}}{\text{Headway}} \times 2 = \text{Number of trains passing a single point from both directions in one hour}$$

d. Calculate the total number of trains that would pass a single point from both directions within a given period by multiplying the answer from Equation B-1 with the number of hours that are in the period (see Equation B-2).

**Equation B-2: Total number of trains passing a single point from both directions within a given period**

$$\text{Number of trains passing a single point from both directions in one hour} \times \text{Number of hours within a given period (e.g., peak period)} = \text{Total number of trains passing a single point from both directions within a given period}$$

e. Sum up the number of trains that would pass a single point from both directions on a daily basis for the different days of the week (e.g., weekday).

f. Calculate the annual number of trains that would pass a single point from both directions using Equation B-3.

**Equation B-3: Annual number of trains passing a single point from both directions**

$$\left(\text{Total daily number of trains passing a single point on a weekday} \times \text{Number of weekdays in 2021}\right) + \left(\text{Total daily number of trains passing a single point on a Saturday} \times \text{Number of Saturdays in 2021}\right) + \left(\text{Total daily number of trains passing a single point on a Sunday /holiday} \times \text{Number of Sundays/ holidays in 2021}\right) = \text{Annual number of trains passing a single point}$$

g. Multiply the annual number of trains passing a single point by the total travel time from Commercial Dr. to UBC to get annual revenue train hours. Then, to calculate the annual vehicle hours of revenue service, multiply the revenue train hours by 3 for LRT and 4 for SkyTrain (to account for the average number of vehicles per train).

*Results*

All of the results are shown in Tables B-2 to B-4.

**Table B-2: Total number of weekdays, Saturdays, Sundays, and holidays in 2021**

| Day of Week | Total Days in 2021 |
|---|---|
| Weekdays | 253 |
| Saturdays | 52 |
| Sundays and holidays | 60 |

**Table B-3: LRT operations**

| Day of Week | Time of Day | Total Duration (hours) | Headway (minutes) | Trains/Hour Passing a Single Point from Both Directions | Total Trains Passing a Single Point | Annual Number of Trains Passing a Single Point |
|---|---|---|---|---|---|---|
| Weekdays | Early morning – 5am to 6am | 1 | 5.5 | 22 | 22 | 131,056 |
| | Peak – 6am to 6:30pm | 12.5 | 4.5 | 27 | 333 | |
| | Evening – 6:30pm to 12am | 5.5 | 5.5 | 22 | 120 | |
| | Late evening – 12am to 2:30am | 2.5 | 7 | 17 | 43 | |
| | **Total** | **21.5** | | | **518** | |
| Saturdays | Early morning – 5am to 9am | 4 | 8 | 15 | 60 | 19,407 |
| | Mid-day 9am to 5pm | 8 | 6 | 20 | 160 | |
| | Evening – 5pm to 10pm | 5 | 7 | 17 | 86 | |
| | Late evening – 10pm to 2:30am | 4.5 | 8 | 15 | 68 | |
| | **Total** | **21.5** | | | **373** | |
| Sundays | Early morning – 6am to 8:30 | 2.5 | 8 | 15 | 38 | 21,150 |
| | Mid-day 8:30am to 7pm | 10.5 | 6 | 20 | 210 | |
| | Evening – 7pm to 12am | 5 | 8 | 15 | 75 | |
| | Late evening – 12am to 2am | 2 | 8 | 15 | 30 | |
| | **Total** | **20** | | | **353** | |
| **Grand Total** | | | | | | **171,613** |
| **Travel Time between Commercial Dr. and UBC (minutes)** | | | | | | **32** |
| **Annual Train Hours of Revenue Service** | | | | | | **91,527** |
| **Annual Vehicle Hours of Revenue Service** | | | | | | **274,581** |

**Table B-4: SkyTrain operations**

| Day of Week | Time of Day | Total Duration (hours) | Headway (minutes) | Trains/Hour Passing a Single Point from Both Directions | Total Trains Passing a Single Point | Annual Number of Trains Passing a Single Point |
|---|---|---|---|---|---|---|
| **Weekdays** | Early morning – 5am to 6am | 1 | 6 | 20 | 20 | **154,457** |
| | Peak – 6am to 9:30am, 3pm to 6:30pm | 7 | 2.5 | 48 | 336 | |
| | Mid-day – 9:30am to 3pm | 5.5 | 5 | 24 | 132 | |
| | Evening – 6:30pm to 10pm | 3.5 | 6 | 20 | 70 | |
| | Late evening – 10pm to 1:30am | 3.5 | 8 | 15 | 53 | |
| | **Total** | **20.5** | | | **611** | |
| **Saturdays** | Early morning – 6am to 9am | 3 | 8 | 15 | 45 | **17,847** |
| | Mid-day 9am to 5pm | 8 | 6 | 20 | 160 | |
| | Evening – 5pm to 10pm | 5 | 7 | 17.1 | 86 | |
| | Late evening – 10pm to 1:30am | 3.5 | 8 | 15 | 53 | |
| | **Total** | **19.5** | | | **343** | |
| **Sundays** | Early morning – 7am to 8:30am | 1.5 | 8 | 15 | 23 | **18,900** |
| | Mid-day 8:30am to 7pm | 10.5 | 6 | 20 | 210 | |
| | Evening – 7pm to 12:30am | 5.5 | 8 | 15 | 83 | |
| | **Total** | **17.5** | | | **315** | |
| **Grand Total** | | | | | | **191,204** |
| **Travel Time between Commercial Dr. and UBC (minutes)** | | | | | | **23** |
| **Annual Train Hours of Revenue Service** | | | | | | **73,295** |
| **Annual Vehicle Hours of Revenue Service** | | | | | | **293,179** |

***Motorized Vehicle Kilometres Traveled (VKT) along the Broadway Corridor***

*Data Sources*

- 2000, 2003, 2004, 2005, 2006, and 2008 weekday 24-hour traffic counts for the Broadway Corridor, from the City of Vancouver (2009b).
- Distance between traffic counters, from VanMap (2008b).

- Total daily bus vehicle-kilometres traveled (VKT) for the #8, #9, #16, #17, and #99 B-Line routes, from September 2008's bus line statistics (TransLink, 2009a) and June 2009 bus schedules and route maps (TransLink, 2009b).

*Approach*

Only the VKT for the Corridor is calculated, as it is assumed that the vehicles diverted to other parallel routes will be more or less offset by the overall reduction in vehicles as a result of the UBC Line coming into operation.

**1. Bus VKT along the Corridor**

a. Calculate the <u>2008/09 daily bus VKT</u> (revenue and non-revenue) <u>along the Corridor by the #9, #17, and B-Line bus routes</u> on weekdays, Saturdays, Sundays, and holidays using Equation B-4, assuming that the same percentage of revenue VKT and non-revenue VKT are driven along the Corridor (see the results in Table B-5).

**Equation B-4: 2008/2009 daily kilometres traveled along the Corridor by the #9, #17, and B-Line bus routes**

| 2008/09 total daily VKT of the #9, #17, and B-Line bus routes | - | 2008/09 total daily VKT of the #9, #17, and B-Line bus routes not driven along the Corridor | = | 2008/09 daily VKT traveled along the Corridor by the #9, #17, and B-Line bus routes |
|---|---|---|---|---|

b. Calculate the <u>2008/09 daily VKT driven along the Corridor by the #8 and #16 bus routes</u> by measuring the distance of the Broadway segment along which they operate and multiplying it by the number of trips made daily (see the results in Table B-5).

c. Calculate the <u>2021 annual bus VKT that will be driven along the Corridor</u> by taking the following steps:
   - Base case: multiply the results of steps a and b by the number of weekdays, Saturdays, Sundays, and holidays in 2021, sum all of results together, and multiply the total by the expected annual bus VKT growth rate. 1.5% is the annual VKT growth rate used in this calculation, as it is assumed transit demand will continue to rise through the years but the increasingly restrained transit capacity along the Corridor will limit the bus VKT growth rate (see the results in Table B-5).
   - LRT and SkyTrain alternatives: assume that the B-Line will no longer operate in 2021 and that the service of the #17 bus will be reduced by half; the bus VKT in 2021 will therefore be 46% of what is calculated for the base case (see the results in Table B-7).

**2. Total VKT along the Corridor**

a. Calculate the <u>average 24-hour weekday traffic volume for each direction</u> using the traffic counter data.

b. Calculate the <u>2008/09 total daily weekday VKT between each pair of traffic counters</u> by multiplying the distance between the traffic counters with the traffic volume heading in each direction (assuming the traffic volumes in 2008/09 are still similar to those of 2000, 2002, 2003, 2004, 2005, 2006). For example, if traffic counter A measures 1000 vehicles heading east, and the next traffic counter to the east is 1.2 km away, then the formula would be:

1000 vehicles x 1.2 km = 1200 vehicle-km

c. Calculate the 2008/09 total annual VKT along the Corridor, assuming that overall there is 20% less traffic on weekends. Since no counters were located along the Broadway segment where the #8 bus route operates, add the Broadway kilometres of this bus route to the total that was calculated using the traffic counter data (see results in Table B-6).
d. Assume the 2021 total annual VKT along the Corridor for the base case will be approximately the same as the 2008/09 total annual VKT.
e. Calculate the 2021 annual passenger vehicle kilometres traveled (passenger VKT) along the Corridor by following these steps:
    - Base case: subtract the 2021 annual bus VKT along the Corridor from the result of step d (see Equation B-5).

**Equation B-5: 2021 annual passenger VKT along the Corridor in the base case**

| | | | | |
|---|---|---|---|---|
| 2021 total annual VKT along the Corridorin the base case | - | 2021 annual bus VKT along the Corridor in the base case | = | 2021 annual passenger VKT along the Corridor in the base case |

    - LRT and SkyTrain options: assume that the passenger VKT along the Corridor will be reduced by 20% and 15%, respectively (see Equation B-6). There will be a higher reduction of passenger VKT in the LRT scenario, as there will be reduced road capacity. Some of this traffic, however, may be diverted onto alternate routes.

**Equation B-6: Annual passenger VKT along the Corridor in 2021 in the LRT/SkyTrain scenarios**

| | | | | |
|---|---|---|---|---|
| 2021 annual passenger VKT along the Corridor in the base case | x | 100%- (Percent reduction in passenger VKT along the Corridor as a result of the LRT/SkyTrain being implemented) | = | 2021 annual passenger VKT along the Corridor in the LRT/SkyTrain scenarios |

f. Calculate the 2021 total annual VKT along the Corridor for the LRT and SkyTrain options by summing together the annual passenger and bus VKT.

*Results*

The results of the above calculations are shown in Tables B-5 to B-7.

**Table B-5: 2008/09 and 2021 base case annual bus VKT**

| Bus Route | Annual VKT (VKT) | Percentage of Total Current Bus VKT |
|---|---|---|
| #9 | 964,383 | 33.3% |
| #17 | 546,004 | 18.9% |
| #99 B-Line | 1,247,384 | 43.11% |
| #16 | 58,788 | 2.03% |
| #8 | 77,193 | 2.67% |
| 2008/09 total | 2,893,752 | |
| Annual growth rate of bus VKT | 1.5% | |
| **2021 Total** | **3,408,692** | |

**Table B-6: 2008/09 base case total daily and annual VKT (passenger vehicles and bus) along the Corridor**

| | |
|---|---|
| 2008/09 total VKT along the Corridor on a typical weekday over 24 hours | 285,676 |
| Total annual VKT | 97,872,462 |

**Table B-7: 2021 annual VKT for the base case and for the LRT and SkyTrain scenarios**

| Mode | Base Case | LRT | SkyTrain |
|---|---|---|---|
| Buses | 3,408,692 | 1,567,998 | 1,567,998 |
| Passenger vehicles | 94,463,770 | 75,571,016 | 80,294,204 |
| **Total** | **97,872,462** | **77,139,014** | **81,862,203** |

### *Ridership*

*Data Sources*

- UBC student, faculty, and staff populations from 2000 to 2008, from the UBC Office of Planning and Institutional Research (2008).
- Information regarding future student, faculty, and staff population growth trends, from UBC Campus and Community Planning (personal communication, March 20, 2009).
- Number of student, faculty, and staff residential units at the UBC campus in the fall of 2007, from UBC Campus and Community Planning (2007).
- Number of student, faculty, and staff residential units at the UBC campus in 2012, 2021, and once the campus is completely built out, from the *UBC Comprehensive Community Plan* (UBC, 2000), the *UBC Official Community Plan* (Metro Vancouver, 1997), the *UBC Housing Matrix* (UBC Campus and Community Planning, 2005), and the UBC University Town website (UBC, n.d.)
- Number of daily trips (on all modes) made on a typical weekday by the UBC population from 1997 to 2008, from the UBC *Transportation Status Reports* (2004-2008).

- Number of daily transit trips made on a typical weekday by the UBC population from 1997 to 2008, from the UBC *Transportation Status Reports* (2004-2008).
- Proportion of transit trips made on the #99 B-Line bus route on a typical weekday by the UBC population from 2005 to 2008, from the UBC *Transportation Status Reports* (2004-2008).
- Total annual passenger boardings on the #99 B-Line bus route for 2006 and 2008, from TransLink (information for 2007 was unavailable) (personal communication, March 20, 2009).
- Projected residential and employment populations for 2021 in the traffic area zones that contain the Broadway Corridor, from modeling work done by the City of Vancouver and Metro Vancouver (personal communication, April 6, 2009).

*Approach*

**1. Calculate the ridership going to and from UBC**

a. Calculate the <u>2008 total UBC population</u> by summing the student, faculty, and staff populations together.

b. Calculate the <u>2021 student, faculty, and staff populations</u> by applying the following assumptions:
   - The undergraduate student annual growth rate between 2008 and 2017 will be 0.5%.
   - The graduate student annual growth rate between 2008 and 2017 will be 1.5%.
   - The faculty/staff annual growth rate between 2008 and 2017 will be 0.75%.
   - There will be no growth in the total student, faculty, and staff populations after 2017.

c. Calculate the <u>2021 UBC on-campus population</u> (those students/faculty/staff who are living on campus), assuming that:
   - Each market unit has an average of one student, faculty, or staff member.
   - None of the market housing units are owned by students.

d. Calculate the <u>total UBC commuting population in 2008 and 2021</u> by subtracting the on-campus population from the total UBC population for those two years (see Equation B-7).

**Equation B-7: 2008 and 2021 total commuting population**

| | | | | |
|---|---|---|---|---|
| 2008 or 2021 UBC total population | – | 2008 or 2021 on-campus UBC population | = | 2008 or 2021 total UBC commuting population |

e. Calculate the <u>average daily number of transit trips made per UBC commuter on a typical weekday in 2008</u> by using Equation B-8.

**Equation B-8: 2008 daily transit trips per UBC commuter**

$$\text{2008 daily number of UBC transit trips} \times \frac{1}{\text{2008 total UBC commuting population}} = \text{2008 average daily number of transit trips made per UBC commuter on a typical weekday}$$

f. Calculate the <u>2021 average daily number of transit trips made per UBC commuter on a typical weekday</u> by applying the following assumptions and Equation B-9:
   - Base case: the average daily number transit trips made per commuter on a typical weekday will increase by 1.5% each year between 2008 and 2021. This is based on the following assumptions:
      - There will continue to be incentives to use public transit (e.g., increased parking rates and reduced parking availability, increased fuel prices, etc.);
      - All new undergraduate students will use their U-Pass;
      - Student transit riders leaving UBC will be offset by new and existing faculty/staff transit riders; and
      - The transit system is currently at capacity so increases to ridership in the near future will be restricted (in fact, the 2008 *Transportation Status Report* indicated that transit ridership actually dropped between 2007 and 2008).
   - LRT option: the average daily number of transit trips made per commuter on a typical weekday will increase by 1.5% each year between 2008 and 2019, by 4% between 2019 and 2020, and by 8% in the following year. The jump in growth in 2019-2021 will be attributed to the enhanced transit capacity and travel time savings provided by the LRT.
   - SkyTrain option: the average daily number of transit trips made per commuter on a typical weekday will increase by 1.5% each year between 2008 and 2019, by 5% between 2019 and 2020, and by 10% in the following year. The reasons for this change in growth after 2019 are the same as the LRT option.

**Equation B-9: Average daily weekday transit trips made per commuter**

$$\text{\% change in average daily number of transit trips made per commuter between years x and x+1} \times \text{Average daily transit trips made per commuter on a typical weekday in year x} = \text{Average daily transit trips made per commuter on a typical weekday in year x+1}$$

g. Calculate the <u>total daily number of weekday transit trips made in 2021 for the base case, and the LRT and SkyTrain cases</u> by multiplying the average daily number of weekday trips made per commuter with the total number of commuters (see Equation B-10).

**Equation B-10: 2021/22 total daily number of transit trips to/from UBC**

| | | | | |
|---|---|---|---|---|
| 2021 average daily number of transit trips made per UBC commuter on a typical weekday | x | 2021 total number of UBC commuters | = | 2021 total daily number of UBC weekday transit trips |

h. Calculate the <u>2021 total daily number of trips made on the B-Line/LRT/SkyTrain</u> using the following assumptions and Equation B-11:
   - Base case: As a result of no significant changes being made to the existing transit-supportive infrastructure, the proportion of UBC transit trips made on the B-Line route in 2021 will be the same as 2008 (38.2%).
   - LRT option:
     - All of the Broadway Corridor riders new to transit will be using the UBC Line;
     - Some of the riders currently on bus routes #33, #9, #4, and #25 (which in 2008, collectively made up 16.9% of the transit trips to UBC) will switch to the UBC Line; and
     - Bus routes #84 and #17 (which in 2008, made up 12.9% of the transit trips to UBC) will no longer be operating and the ridership will be transferred to the UBC Line.

     Therefore, the UBC Line will share 55.1% of all transit trips made to and from the university.
   - SkyTrain option: same assumptions as for the LRT option, except that the UBC Line will make up 57.1% of all transit trips made to and from UBC.

**Equation B-11: 2021 total daily passenger trips on the B-Line/LRT/SkyTrain**

| | | | | |
|---|---|---|---|---|
| 2021 of total daily number of UBC weekday transit trips | x | 2021 proportion of transit trips made on B-Line/LRT/SkyTrain | = | 2021 total daily passenger trips for B-Line/LRT/SkyTrain |

i. Calculate the <u>total annual number of UBC trips made on the B-Line in 2006 and 2008, and on the B-Line (base case), LRT and SkyTrain (alternatives) in 2021</u> using the following assumptions and Equation B-12:
   - The UBC commuting population and the overall UBC community share the same profile.
   - There are approximately 152.8 and 240 working days during which students and faculty/staff travel to and from UBC, respectively.

**Equation B-12: Total annual number of trips made on the B-Line, LRT or SkyTrain in 2021**

| Total student or faculty/staff commuting population in 2021 | x | Number of working days in 2021 | = | Total annual number of trips made on the B-Line/LRT/SkyTrain in 2021 |
|---|---|---|---|---|

## 2. Calculate the ridership not originating from or destined for UBC (non-UBC trips)

a. Calculate the non-UBC B-line boardings for 2006 and 2008 by subtracting the UBC B-line boardings from the total B-Line boardings (see Equation B-13).

**Equation B-13: 2006 or 2008 non-UBC B-line boardings**

| 2006 or 2008 total B-Line boardings | – | 2006 or 2008 total UBC B-line boardings | = | 2006 or 2008 non-UBC B-Line boardings |
|---|---|---|---|---|

b. Calculate the change in non-UBC B-Line boardings between 2006 and 2008.

c. Calculate the 2009 to 2021 annual non-UBC B-line boardings by applying the following assumptions and Equations B-14 and B-15:

- Base case, between 2009 and 2021:
  - The average annual residential and employment population growth rate of the Corridor will be 0.9%;
  - There will continue to be incentives to use transit (e.g., increased parking rates, reduced parking availability, and increased fuel prices). However, due to increasingly restrained transit capacity, the annual growth rate of transit trips made per person along the Corridor will only be 1.5%; and
  - The B-Line's share of transit trips made along the Corridor will remain the same.
- LRT option:
  - Between 2009 and 2014, the Corridor's average annual residential and employment population growth rate will be 0.9%; after 2015, however, in anticipation of the LRT line being built, more residential and employment developments will be attracted to the area and therefore the annual population growth rate will gradually increase, reaching 5% in 2021;
  - Between 2009 and 2019, the annual growth rate of transit trips made per person along the Corridor will be 1.5%. Then, in 2020 and 2021, due to increased transit capacity, the number of transit trips made per person along the Corridor will increase by 4% and 8%, respectively. The latent demand for transit may be somewhat offset by the higher number of amenities within walking/cycling distance; and
  - Between 2009 and 2019, the B-Line's share of transit trips made along the Corridor will remain the same (38.2%); in 2020 and 2021, however, due to travel time savings, the LRT's share of transit trips made along the Corridor will be 44.3%.

- SkyTrain option:
  - Between 2009 and 2014, the Corridor's average annual residential and employment population growth rate will be 0.9%; after 2015, however, in anticipation of the SkyTrain line being built, more residential and employment developments will be attracted to the area and therefore the annual population growth rate will gradually increase, reaching 5% in 2021;
  - Between 2009 and 2019, the annual growth rate of transit trips made per person along the Corridor will be 1.5%; in 2020 and 2021, however, due to increased transit capacity, the number of transit trips made per person along the Corridor will increase by 5% and 10%, respectively. The latent demand for transit may be somewhat offset by the higher number of amenities within walking/cycling distance; and
  - Between 2009 and 2019, the B-Line's share of transit trips made along the Corridor will remain the same (38.2%); in 2020 and 2021, however, due to travel time savings, the SkyTrain's share of transit trips made along the Corridor will be 49.6%.

**Equation B-14: Annual growth rate of B-Line/LRT/SkyTrain trips**

| | | | | | | |
|---|---|---|---|---|---|---|
| Annual residential and employment population growth rate between years x and x+1 | x | Annual growth rate of transit trips made per person along the Corridor between years x and x+1 | x | B-Line/LRT/ SkyTrain's share of transit trips made along the Corridor in year x+1 | = | Annual growth rate of B-Line/LRT/ SkyTrain trips between year x and x+1 |

**Equation B-15: Total trips made on the B-Line/LRT/SkyTrain**

| | | | | |
|---|---|---|---|---|
| Annual growth rate of B-Line/LRT/SkyTrain trips between year x and x+1 | x | Number of B-Line/LRT/SkyTrain Trips in year x | = | Total trips made on the B-Line, LRT, or SkyTrain for year x+1 |

## 3. Add the UBC and non-UBC trips together

a. Calculate the total trips made along the Corridor in 2021 on the B-Line (base case) and on the LRT and SkyTrain systems (alternatives) by using Equation B-16.

**Equation B-16: 2021 total trips on B-Line/LRT/SkyTrain**

| | | | | |
|---|---|---|---|---|
| 2021 UBC trips on B-Line/LRT/SkyTrain | + | 2021 non-UBC trips on B-Line/LRT/SkyTrain | = | 2021 total trips on B-Line/LRT/SkyTrain |

*Results*

## 1. Ridership going to and from UBC

The results for UBC ridership are shown in Table B-8.

**Table B-8: Results for UBC ridership**

| Measurement | Result |
|---|---|
| a. 2008 UBC student, faculty, and staff population | 57,650 |
| b. 2021 UBC student, faculty, and staff population | 61,430 |
| c. 2021 UBC on-campus population | 15,190 |
| d. 2008 and 2021 UBC commuting population | 2008: 45,360<br>2021: 46,250 |
| e. 2008 average daily number of transit trips made per UBC commuter on a typical weekday | 1.12 |
| f. 2021 average daily number of transit trips made per UBC commuter on a typical weekday | Base case: 1.36<br>LRT option: 1.49<br>SkyTrain option: 1.53 |
| g. 2021 total daily number of weekday transit trips made | Base case: 63,110<br>LRT option: 68,810<br>SkyTrain option: 70,750 |
| h. 2021 total daily number of trips made on the B-Line/LRT/SkyTrain | B-Line: 24,090<br>LRT option: 37,910<br>SkyTrain option: 40,400 |
| i. Total annual number of trips made in 2006 and 2008 on the B-Line and in 2021 on the B-Line (base case), LRT and SkyTrain (alternatives): | 2006 B-Line: 2,716,600<br>2008 B-Line: 3,338,720<br>2021 B-Line: 4,133,180<br>2021 LRT option: 6,503,780<br>2021 SkyTrain option: 6,930,670 |

## 2. Ridership not originating from or destined for UBC (non-UBC trips)

The results for the non-UBC ridership calculations are shown in Table B-9.

**Table B-9: Results for non-UBC ridership**

| Measurement | Result |
|---|---|
| a. 2006 and 2008 non-UBC B-Line boardings | 2006: 8,273,400<br>2008: 9,501,280 |
| b. % change in non-UBC B-Line boardings between 2006 and 2008 | +14.8% |
| c. 2009 and 2021 non-UBC B-line boardings | 2009: 9,730,590<br>2021 base case: 12,954,650<br>2021 LRT option: 32,538,300<br>2021 SkyTrain option: 35,932,590 |

### *Residential Densities of Study Areas*

Table B-10 shows the projected residential densities of the transit station study areas. More details on how this information was used in this study can be found in Subsection 4.2.3.

**Table B-10: 2021 projected population densities for station study areas**

| Station Study Area | Combined Residential and Employment Density (persons/ha) |
|---|---|
| Commercial | 86 |
| Clark | 108 |
| Great Northern Way | 88 |
| Fraser | 111 |
| Main | 148 |
| Cambie | 203 |
| Oak | 216 |
| Granville | 175 |
| Arbutus | 159 |
| Macdonald | 101 |
| Alma | 50 |
| Sasamat | 35 |

### *Volume of Concrete Used*

*Data Sources*

- Concrete quantities for station components and guideway for Portland Transit Mall line segment, from TriMet (2009a).
- Concrete quantities for stations and bored tunnel sections of the Canada Line, from IBI Group (2009).
- Height and width of SkyTrain and Canada Line vehicles, from Fisher (personal communication, July 8, 2009).
- Depth of regular sidewalks, from Parkinson and Fisher (1996).
- Depth of LRT station platforms on top of regular sidewalks, from TriMet (2009a).
- Width and length of LRT station platforms, from designs developed in the 1999 *Beyond the B-Line* report.
- Density of concrete, from Boyden (2009).

*Approach*

- Calculate the volume of concrete used per station component, per kilometre of guideway, and per kilometre of mountable curb for LRT, assuming the following dimensions:
  - Station platform: width of 3.7 m, length of 100 m, and a depth of 27.5 cm.
  - Guideway: width of 3 m and a depth of 33 cm, and 60% of it will be covered with grass or other plants.
  - Mountable curb: width of 20cm and a depth of 15cm.

- Calculate the average volume of concrete used per station and per kilometre of bored tunnel for SkyTrain, assuming that:
  - The volume of concrete used to build the elevated and underground Canada Line Stations is approximately the same, and SkyTrain stations would be similarly sized and designed.
  - The bored tunnels of the SkyTrain line would have an internal diameter of 3.9 m (1.4 m smaller than the Canada Line tunnel), and therefore the volume of concrete used per kilometre is 73.6% of that of the Canada Line.

*Results*

The results for the LRT and SkyTrain options are shown in Table B-11.

**Table B-11: Volume of concrete used for stations and guideway**

| **Station Component** | **LRT** | **SkyTrain** |
|---|---|---|
| Station platform ($m^3$) | 64.75 | - |
| Foundation for tactile warning pavers ($m^3$) | 37.21 | - |
| Shelter foundations ($m^3$) | 2.67 | - |
| Light pole foundations ($m^3$) | 2.01 | - |
| Catenary pole foundations ($m^3$) | 4.00 | - |
| Traffic signal pole foundations ($m^3$) | 1.91 | - |
| Wayfinding and info sign foundations ($m^3$) | 1.91 | - |
| Artwork foundations ($m^3$) | 0.57 | - |
| **Total per station ($m^3$)** | **115.03** | **4,062.50** |
| **Total for 12 stations ($m^3$)** | **1380.38** | **44,687.50** |
| **Guideway** | **LRT** | **SkyTrain** |
| Per km of guideway ($m^3$) | 396 | 9,813 |
| **Total for 26.8 km of guideway ($m^3$)** | **10,613** | **262,997** |
| Per km of mountable curb ($m^3$) | 30 | - |
| **Total for 26.8 km of mountable curb ($m^3$)** | **804** | - |
| **Total volume for stations, guideway, and mountable curb ($m^3$)** | **12,827** | **308,519** |
| Density of concrete ($kg/m^3$) | 2,242 | |
| **Total weight of concrete used (tonne)** | **28,759** | **691,699** |

***Environmental Impacts of Concrete Production***

*Data*

- Typical concrete mixing ratios, from Dettman (2009).
- Percentage of cement typically replaced by fly ash, a by-product from coal fired power plants, in the average concrete mix in the Vancouver region, from EcoSmart Concrete (*Ibid*).
- $CO_2$, NOx, and PM10 emission factors for cement, from EcoSmart Concrete (2009) .

- Water, limestone, and shale consumption rates for cement production from EcoSmart Concrete (*Ibid*).

*Approach*

a. Convert the volume of concrete calculated in the previous section to a weight measurement (tonne).
b. Calculate the amount the cement, water, sand, and gravel used to produce each tonne of concrete, assuming that in Vancouver 25% of the cement that is typically replaced by fly ash.
c. To determine the emissions released and resources consumed, multiply the $CO_2$, NOx, and PM10 emission factors, and water, limestone, and shale consumption rates by the amount of cement and concrete used.

*Results*

The results for the LRT and SkyTrain options are shown in Table B-12.

**Table B-12: Concrete production - emissions produced and resources consumed**

| Emission/Resource | Emissions Produced or Resources Consumed (tonne) per Tonne of Cement Produced | Total Emissions Produced or Resources Consumed (tonne) for LRT Construction | Total Emissions Produced or Resources Consumed (tonne) for SkyTrain Construction |
|---|---|---|---|
| $CO_2$ | 1 | 3,400 | 82,710 |
| NOx | 0.003 | 10 | 245 |
| PM10 | 0.0004 | 1 | 33 |
| Limestone and shale | 2 | 6,800 | 163,420 |
| **Material** | **Percentage of Concrete Mix** | **Total Volume of Material (tonne) used for LRT Construction** | **Total Volume of Material (tonne) used for SkyTrain Construction** |
| Fly ash | 4% | 1,130 | 27,240 |
| Cement | 12% | 3,400 | 81,710 |
| Water | 8% | 2,210 | 53,210 |
| Sand | 33% | 9,590 | 230,570 |
| Gravel | 43% | 12,430 | 298,980 |

***Emissions from Motorized Construction Equipment***

*Approach*

- Once information on the type of construction equipment that would likely be used to build the LRT and SkyTrain options, as well as the amount of fossil fuels they will likely use up is compiled, a software program such as NONROAD2002a can be used to convert the values into units of emissions produced. NONROAD2002a is an emissions inventory model developed by the US Environmental Protection Agency that predicts the amount of air pollutants that are produced from non-road mobile sources under various conditions. Further information can be found on the US Environmental Protection Agency Transportation and Air Quality website (US EPA, 2009).

# Appendix C - Sensitivity Analysis

In this study, a range of assumptions has been made for the MAE analysis. While some are well-documented projections, others are informed estimates. Some can also be described as rough estimates. These assumptions can vary due to the economic, social, and environmental conditions.

To investigate the effects of these possible variations, a sensitivity analysis has been performed in which key parameters have been altered. Similar to the Canada Line MAE, this sensitivity analysis is divided into several areas:

- Variations in trip making and travel preferences
- Variations in service levels
- Variations in financial assumptions
- Variations in design

Within each of these categories, the sensitivity of the following parameters is examined:

- Trip making and travel preferences:
    - effects of increased or reduced growth rates for the Corridor, UBC, and the study areas around the stations
    - effects of increased vehicle operating costs
    - effects of walking/cycling trips replacing transit trips
- Service levels:
    - effects of maintaining base bus service with rapid transit
    - effects of changing service frequency or operating hours
- Financial parameters:
    - effects of increased construction costs
- Design criteria
    - effects of changing the construction method for the SkyTrain option

The following sections provide a summary of how these variations will affect the study's outcomes. Only those indicators included in the UBC Line case study have been considered for the sensitivity analysis.

***Trip Making and Travel Preferences***

*Increased or Decreased Population Growth*

In the evaluations, it is assumed that between 2009 and 2014 the Corridor and study areas (which include up to 5 blocks north and south of Broadway) will experience steady residential population and employment growth. Then in 2021, in anticipation of the UBC Line being built, these areas will see a more significant increase. It is also assumed that the UBC population will reach approximately 61,400 by 2017 and will hold steady until at least 2021. If, however, the residential population and/or employment growth along the Corridor and at UBC are lower or higher than projected (e.g., due to changes in the economy, demographics, and/or settlement and employment patterns), then the ridership of the UBC Line may decrease or increase. Similarly, if the population growth of the study areas is different than projected, the ability of the station areas to achieve the minimum rapid transit-supportive density requirements may change. In turn, ridership will affect the capital cost per new passenger relative to the base case, and the operating cost per passenger and per new passenger relative to the base case.

Tables C-1 to C-3 illustrate how changes to the population growth rates by 10% would affect these factors. The following is a description of the assumptions made in the analysis.

1) Broadway Corridor residential and employment population growth rates:
   a) Increased overall growth rates:
      - Base case: between 2009 and 2021 the annual growth rate will be 0.99% (as opposed to 0.9%).
      - LRT and SkyTrain options: between 2009 and 2014 the annual growth rate will be 0.99% (as opposed to 0.9%); after 2015, in anticipation of the LRT line being built, this annual population growth rate will gradually increase, reaching 5.5% (as opposed to 5%) in 2021.
   b) Reduced overall growth rates:
      - Base case: between 2009 and 2021 the annual growth rate will remain at 0.81% (as opposed to 0.9%).
      - LRT and SkyTrain options: between 2009 and 2014 the annual growth rate will be 0.81% (as opposed to 0.9%); after 2015, in anticipation of the LRT line being built, this annual population growth rate will gradually increase, reaching 4.5% (as opposed to 5%) in 2021.
2) UBC population growth rates:
   a) Increased overall growth rates:
      - Between 2009 and 2017 the undergraduate, graduate, and faculty/staff population's growth rates will be 0.55%, 1.65%, and 0.825%, respectively (as opposed to 0.5%, 1.5%, and 0.75%, respectively). After 2017, the populations will remain stable until at least 2021.
   b) Reduced overall growth rates:
      - Between 2009 and 2017 the undergraduate, graduate, and faculty/staff population's growth rates will be 0.45%, 1.35%, and 0.675%, respectively (as opposed to 0.5%, 1.5%, and 0.75%, respectively). After 2017, the populations will remain stable until at least 2021.
3) Study areas residential and employment population growth rates:
   a) Increased overall growth rates
      - For all study areas east of Vine St. (including the study area for the Arbutus station), with the exception of the Great Northern Way Campus station: between 2009 and 2014 the annual growth rate will be 0.99% (as opposed to 0.9%); after that, development will gradually increase, reaching a growth rate of 2.2% (as opposed to 2%) in 2021.
      - For the Great Northern Way Campus station: between 2009 and 2014 the annual residential and employment density will grow by 0.99% (as opposed to 0.9%); after that, due to significant campus developments being built, the employment population

will increase substantially and the population density will rise steadily, reaching an annual growth rate of 4.4% (as opposed to 4%) in 2021.

- For study areas west of Vine St.: between 2009 and 2014 the annual growth rate will be 0.33% (as opposed to 0.3%); after that, development will increase slightly, reaching a growth rate of 0.66% (as opposed to 0.6%) in 2021.

b) Reduced overall growth rates

- For all study areas east of Vine St. (including the study area for the Arbutus station), with the exception of the Great Northern Way Campus station: between 2009 and 2014 the annual growth rate will be 0.81% (as opposed to 0.9%); after that, development will gradually increase, reaching a growth rate of 1.5% (as opposed to 1.8%) to in 2021.
- For the Great Northern Way Campus station: between 2009 and 2014 the annual residential and employment density will grow by 0.81% (as opposed to 0.9%); after that, due to significant campus developments being built, the employment population will increase substantially and the population density will rise steadily, reaching an annual growth rate of 3.6% (as opposed to 4%) in 2021.
- For study areas west of Vine St.: between 2009 and 2018 the annual growth rate will be 0.27% (as opposed to 0.3%); after that, development will increase slightly, reaching a growth rate of 0.54% (as opposed to 0.6%) in 2021.

**Table C-1: Effects of changing the Corridor's population growth rates**

| | | Increased Growth Rates | Reduced Growth Rates | Absolute Difference from the MAE Analysis | % Difference from the MAE Analysis |
|---|---|---|---|---|---|
| **LRT** | Total ridership | 39.7 million | 38.4 million | +/-700,000 | +/-2% |
| | New ridership relative to base case | 22.5 million | 21.4 million | +/-500,000 | +/-3% |
| | Capital cost per new passenger | $24 to $36 | $25 to 37 | +/-($0.60 to 0.90) | +/-3% |
| | Annual operating cost per passenger | $1.60 | $1.65 | +/-$0.03 | +/-2% |
| | Annual operating cost per new passenger relative to base case | $2.82 | $2.96 | +/-$0.07 | +/-3% |
| | Gross annual operating revenue | $75.1 million | $72.5 million | +/-$1.3 million | +/-2% |
| **SkyTrain** | Total ridership | 43.6 million | 42.1 million | +/-800,000 | +/-2% |
| | New ridership relative to base case | 26.4 million | 25.2 million | +/-600,000 | +/-2% |
| | Capital cost per new passenger | $83 to 106 | $87 to 111 | +/-($2 to 3) | +/-2% |
| | Annual operating cost per passenger | $0.60 | $0.62 | +/-$0.01 | +/-2% |

| | | Increased Growth Rates | Reduced Growth Rates | Absolute Difference from the MAE Analysis | % Difference from the MAE Analysis |
|---|---|---|---|---|---|
| | Annual operating cost per new passenger relative to base case | $0.99 | $1.04 | +/-$0.02 | +/-2% |
| | Gross annual operating revenue | $82.5 million | $79.6 million | +/-$1.4 million | +/-2% |

**Table C-2: Effects of changing UBC's population growth rates**

| | | Increased Growth Rates | Reduced Growth Rates | Absolute Difference from MAE Analysis | % Difference from MAE Analysis |
|---|---|---|---|---|---|
| **LRT** | Total ridership | 39.1 million | 38.4 million | +/-60,000 | +/-0.1% |
| | New ridership relative to base case | 22.0 million | 21.4 million | +/-120,000 | +/-0.1% |
| | Capital cost per new passenger | $25 to 36 | $25 to 36 | +/-($0.02 to 0.03) | +/-0.1% |
| | Annual operating cost per passenger | $1.62 | $1.63 | +/-$0.00 | +/-0.1% |
| | Annual operating cost per new passenger relative to base case | $2.89 | $2.89 | +/-$0.00 | +/-0.1% |
| | Gross annual operating revenue | $73.9 million | $73.7 million | +/-$100,000 | +/-0.1% |
| **SkyTrain** | Total ridership | 42.9 million | 42.8 million | +/-$60,000 | +/-0.1% |
| | New ridership relative to base case | 25.8 million | 25.8 million | +/-20,000 | +/-0.1% |
| | Capital cost per new passenger | $85 to 109 | $85 to 109 | +/-$0.10 | +/-0.1% |
| | Annual operating cost per passenger | $0.61 | $0.61 | +/-$0.00 | +/-0.1% |
| | Annual operating cost per new passenger relative to base case | $1.01 | $1.01 | +/-$0.00 | +/-0.1% |
| | Gross annual operating revenue | $81.1 million | $80.9 million | +/-$100,000 | +/-0.1% |

**Table C-3: Effects of changing the study areas' population growth rates**

| | Reduced Study Area Growth Rates | | Increased Study Area Growth Rates | |
|---|---|---|---|---|
| | Result | Difference from MAE Analysis | Result | Difference from MAE Analysis |
| **Ability of Study Areas to Achieve LRT-Supportive Densities** | All study areas able to achieve the minimum LRT-supportive density | No changes from the original MAE analysis | All study areas able to achieve the minimum LRT-supportive density | No changes from the original MAE analysis |
| **Ability of Study Areas to Achieve SkyTrain-Supportive Densities** | 8 out of 10 study areas able to achieve the minimum SkyTrain-supportive density | No changes from the original MAE analysis | 8 out of 10 study areas able to achieve the minimum SkyTrain-supportive density | No changes from the original MAE analysis |

As Tables C-1 and C-2 indicate, changes to the Corridor's population growth rates will have a much larger effect on the UBC Line's ridership and other financial indicators than changes to the UBC population. Meanwhile, varying the study areas' population growth rates appear to have no effect the areas' ability to reach the minimum recommended LRT- and SkyTrain-supportive densities (see Table C-3).

*Increased Vehicle Operating Costs*

Due to growing energy shortages, the price of fuel may increase significantly more than assumed in the MAE analysis. Additionally, to meet their GHG reduction targets under Bill 27, the City of Vancouver and the Province of BC may significantly increase parking and vehicle insurance fees, respectively. These changes will affect travel behaviour, causing people to shift modes and/or live closer to where they work, the latter of which would reduce the kilometres they travel on a daily basis.

To quantify the effect of increased vehicle operating costs on transit ridership, the measurement of elasticity is used. Elasticity is the percentage change in consumption of a good caused by a 1% change in its price or other characteristics (such as traffic speed or road capacity). For example, an elasticity of -0.3 for vehicle use with respect to vehicle operating expenses means that each 1% increase in these costs results in a 0.3% reduction in vehicle mileage or trips.

The following elasticities for vehicle operating costs are taken from Litman's report, *Transport Elasticities* (2008c):

- Transit ridership: 0.1
- VKT: -0.5

To account of the effect increased vehicle operating costs would have on transit ridership, the following assumptions are made:

- The vehicle operating costs will increase by 20%;
- Annual growth rate of daily transit trips made per person along the Corridor:
    - Base case: 2% (as opposed to 1.5%) between 2009 and 2021

- LRT option: 2% (as opposed to 1.5%) between 2009 and 2019, 5.3% between 2019 and 2020, and 10.7% in the following year (as opposed to 4% and 8%, respectively).
- SkyTrain option: 2% (as opposed to 1.5%) between 2009 and 2019, 6.7% between 2019 and 2020, and 13.3% in the following year (as opposed to 5% and 10%, respectively).

- Between 2009 and 2021 the annual growth rate for bus VKT is 2% (as opposed to 1.5%).
- The passenger VKT:
  - Base case: between 2009 and 2021 passenger VKT will decrease annually by 10% (as opposed to no change).
  - LRT option: between 2009 and 2020 passenger VKT will decrease annually by 10% (as opposed to no change), and then by 28% in 2021.
  - SkyTrain option: between 2009 and 2020 passenger VKT will decrease annually by 10% (as opposed to no change), and then by 23.5% in 2021.

Table C-4 summarizes the results of this analysis.

**Table C-4: Effects of increasing vehicle operating costs**

| | | Increased Vehicle Operating Costs | | |
|---|---|---|---|---|
| | | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** |
| **LRT** | Total ridership | 42.7 million | +3.7 million | +10% |
| | New ridership relative to base case | 24.6 million | +2.6 million | +12% |
| | Capital cost per new passenger relative to base case | $22 to 33 | -($3 to 4) | -11% |
| | Annual operating cost per passenger | $1.48 | -$0.14 | -9% |
| | Annual operating cost per new passenger relative to base case | $2.58 | -$0.31 | -11% |
| | Gross annual operating revenue | $80.8 million | +$7.0 million | +10% |
| | Cost of traffic services | $196,000 | -$458,000 | -70% |
| | Congestion cost savings relative to base case | $227,500 | -$350,000 | -61% |
| **SkyTrain** | Total ridership | 47.3 million | +4.5 million | +10% |
| | New ridership relative to base case | 29.1 million | +900,000 | +13% |
| | Capital cost per new passenger relative to base case | $76 to 96 | -($10 to 13) | -12% |
| | Annual operating cost per passenger | $0.55 | -$0.06 | -9% |
| | Annual operating cost per new passenger relative to base case | $0.90 | -$0.12 | -12% |
| | Gross annual operating revenue | $89.5 million | +$8.5 million | +10% |
| | Cost of traffic services | $207,000 | -$486,000 | -70% |

| | | Increased Vehicle Operating Costs | | |
|---|---|---|---|---|
| | | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** |
| | Congestion cost savings relative to base case | $194,000 | -$246,000 | -56% |

As shown in Table C-4, increased vehicle operating costs would have significant effects on the ridership of the UBC Line (10-13% increase), as well as on the capital and operating cost per passenger (9-12% reduction), and gross annual operating revenue (10% increase). The cost of traffic services would also be reduced by a dramatic 70%, as there would be less financial resources spent on traffic enforcement, policing, emergency response, etc. In this scenario, however, the congestion cost savings the UBC Line would achieve relative to the base case (no rapid transit) would be lower than the result of the MAE analysis (by 56-61%), as higher vehicle operating costs would have already acted as a disincentive to drive.

*Walking/Cycling Trips Replacing Transit Trips*

Other alternatives to taking transit and driving are walking and cycling. In the case of Downtown Vancouver, a substantial number of trips are now accomplished by foot/bike due to the compactness, high connectivity, and mixed-use nature of the area (TransLink's 2004 trip diary survey indicated that 27% of all trips to Downtown Vancouver were made by walking). If the introduction of the UBC Line leads to similar land use patterns along the Corridor, then walking and cycling could take up a larger share of the total trips made. This, in turn, would affect transit ridership and a number of financial indicators. These results are shown in Table C-5. The assumptions made are as follows:

- The 2020 and 2021 annual growth rates for daily transit trips made per person along the Corridor will be 10% lower than the assumptions used in the MAE analysis.
  - LRT option: the annual growth rate for daily transit trips made per person will be 1.5% between 2009 and 2019, 3.6% between 2019 and 2020, and by 7.2% in the following year (as opposed to 4% and 8% respectively).
  - SkyTrain option: the annual growth rate for daily transit trips made per person will be 1.5% between 2009 and 2019, 4.5% between 2019 and 2020, and by 9% in the following year (as opposed to 5% and 10% respectively).
- The 2020 and 2021 annual growth rates for bus and passenger VKT will be 10% lower than the assumptions used in the MAE analysis.

**Table C-5: Effects of walking/cycling trips replacing transit and passenger vehicle trips**

| | | Walking/Cycling Trips Replacing Transit and Passenger Vehicle Trips | | |
|---|---|---|---|---|
| | | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** |
| **LRT** | Total ridership | 38.4 million | -400,000 | -1% |
| | New ridership relative to base case | 21.4 million | -400,000 | -2% |

| | | Walking/Cycling Trips Replacing Transit and Passenger Vehicle Trips | | |
|---|---|---|---|---|
| | | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** |
| | Capital cost per new passenger (based on ridership levels in 2021) | $26 to 37 | +($0.51 to 0.74) | +2% |
| | Annual operating cost per passenger | $1.64 | +$0.02 | +1% |
| | Annual operating cost per new passenger relative to base case | $2.95 | +$0.06 | +2% |
| | Gross annual operating revenue | $73.0 million | -$800,000 | -1% |
| | Cost of traffic services | $528,000 | -$125,000 | -19% |
| | Congestion cost savings relative to base case | $466,000 | -$111,000 | -19% |
| **SkyTrain** | Total ridership | 42.3 million | -600,000 | -1% |
| | New ridership relative to base case | 25.2 million | -600,000 | -2% |
| | Capital cost per new passenger (based on ridership levels in 2021) | $76 to 96 | +($2 to 3) | +2% |
| | Annual operating cost per passenger | $0.62 | +$0.01 | +1% |
| | Annual operating cost per new passenger relative to base case | $1.04 | +$0.02 | +2% |
| | Gross annual operating revenue | $79.9 million | -$1.2 million | -1% |
| | Cost of traffic services | $561,000 | -$133,000 | -19% |
| | Congestion cost savings relative to base case | $372,000 | -$69,000 | -16% |

If walking and cycling trips replace 10% of the transit and passenger vehicle trips, there would be a small change to the ridership of the UBC Line (1-2% reduction). The same result would be seen for the capital and operating cost per passenger (1-2% increase), and the gross annual operating revenue (1% reduction). However, due to a lower volume of vehicles on the road, the cost of traffic services would be reduced by 19% for both the LRT and SkyTrain options. Similarly, since the congestion cost of the base case would already be much lower, the congestion cost savings relative to the base case would be reduced by 19% for LRT and 16% for SkyTrain.

***Service Levels***

*Maintaining Base Bus Service with Rapid Transit*

If the existing bus service is maintained along with the UBC Line (i.e., the #17 local bus service is not reduced and the B-Line is retained), more of the short local, as well as some of the longer trips, will be met by bus service. In turn, there may be a decrease in the ridership of the UBC

Line, which then affects other financial indicators. These effects are illustrated in Table C-6. The assumptions made in the calculations are as follows:

- LRT option:
  - In 2021, the UBC Line will share 40% (as opposed to 55.1%) of the total transit trips made to and from UBC.
  - In 2021, the UBC Line's share of total transit trips that do not start or end at UBC will only increase by 4.8% (as opposed to 44.3%) compared to the base case.
  - The bus VKT along the Corridor will be the same in 2009 and 2021.
- SkyTrain option:
  - In 2021, the UBC Line will share 45% (as opposed to 57.1%) of the total transit trips made to and from UBC.
  - In 2021, the UBC Line's share of total transit trips that do not start or end at UBC will increase by 17.9% (as opposed to 49.6%) compared to the base case.
  - The bus VKT along the Corridor will be the same in 2009 and 2021.

**Table C-6: Effects of maintaining base bus service with rapid transit**

| | | Maintaining Base Bus Service with Rapid Transit | | |
|---|---|---|---|---|
| | | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** |
| **LRT** | Total ridership | 21.9 million | -17.2 million | -44% |
| | New ridership relative to base case | 4.8 million | -17.2 million | -78% |
| | Capital cost per new passenger relative to base case | $115 to 167 | +($90 to 131) | +359% |
| | Annual operating cost per passenger | $2.90 | +$1.28 | +79% |
| | Annual operating cost per new passenger relative to base case | $13.27 | +$10.38 | +359% |
| | Gross annual operating revenue | $41.3 million | -$32.5 million | -44% |
| | Cost of traffic services | $669,000 | +$16,000 | -2% |
| | Congestion cost savings relative to base case | $467,000 | -$90,000 | -16% |
| **SkyTrain** | Total ridership | 27.8 million | -15 million | -35% |
| | New ridership relative to base case | 10.7 million | -15 million | -59% |
| | Capital cost per new passenger relative to base case | $206 to 262 | +($120 to 153) | +141% |
| | Annual operating cost per passenger | $0.94 | +$0.33 | +54% |
| | Annual operating cost per new passenger relative to base case | $2.44 | +$1.43 | +141% |
| | Gross annual operating revenue | $52.5 million | -$28.5 million | -35% |
| | Cost of traffic services | $709,000 | +$16,000 | -2% |
| | Congestion cost savings relative to base case | $350,000 | -$90,000 | -20% |

As illustrated in Table C-6, maintaining the base bus service would lead to large changes in transit ridership (35-78% reduction). Changes would also be substantial for the capital cost per new passenger (141-359% increase), and gross operating revenue (35-55% decrease). There would, however, be less of an impact on the cost of traffic services (2% reduction). Lastly, due to the high number of transit buses that would continue using the Corridor, in comparison to the MAE analysis results the congestion cost savings relative to the base case would decrease by 16-20%.

*Increased or Reduced Service Frequency or Operating Hours*

If further modeling work indicates that the service frequency or operating hours should be increased or reduced from what has been assumed in this case study, then the total service hours would change. As a result, the operating cost would also change. Tables C-7 and C-8 summarize the results of increasing or reducing service frequency or operating hours. The following assumptions are made to account for these changes:

- Increased or reduced service frequency: the headway for all times of the day will be reduced or increased by 1 minute, respectively.
- Increased or reduced operating hours: the systems will start half an hour earlier and end half an hour later, or start half an hour later and end half an hour earlier, respectively.
- Overall ridership would be affected (according to Litman, the elasticity of ridership with respect to transit service levels is approximately 0.6).

**Table C-7: Effects of changing service frequency**

| | | Reduced Service Frequency | | | Increased Service Frequency | | |
|---|---|---|---|---|---|---|---|
| | | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** | **Result** | **Absolute Difference from MAE Analysis** | **% Difference from MAE Analysis** |
| **LRT** | Total ridership | 35.3 million | -3.7 million | -10% | 44.7 million | +5.6 million | +14% |
| | New ridership relative to base case | 18.2 million | -3.7 million | -17% | 27.6 million | +5.6 million | +26% |
| | Annual vehicle hours of revenue service | 230,700 | -43,900 | -16% | 340,100 | +65,600 | +24% |
| | Capital cost per new passenger | $30 to 44 | +$(5 to 8) | +21% | $20 to 29 | -($5 to 7) | -20% |
| | Total annual operating cost | $53.3 million | -$10.1 million | -16% | $78.6 million | +$15.1 million | +24% |
| | Annual operating cost per passenger | $1.51 | -$0.11 | -7% | $1.76 | +$0.13 | +8% |

| | | Reduced Service Frequency | | | Increased Service Frequency | | |
|---|---|---|---|---|---|---|---|
| | | Result | Absolute Difference from MAE Analysis | % Difference from MAE Analysis | Result | Absolute Difference from MAE Analysis | % Difference from MAE Analysis |
| | Annual operating cost per new passenger relative to base case | $2.93 | +$0.04 | +1.3% | $2.85 | -$0.04 | -1% |
| **SkyTrain** | Total ridership | 37.5 million | -5.4 million | -13% | 53.4 million | +10.5 million | +25% |
| | New ridership relative to base case | 20.4 million | -5.4 million | -21% | 36.3 million | +10.5 million | +41% |
| | Annual vehicle hours of revenue service | 232,780 | -60,400 | -21% | 412,800 | 119,700 | +41% |
| | Capital cost per new passenger | $108 to 137 | +($23 to29) | +27% | $61 to 77 | -($25 to 32) | -29% |
| | Total annual operating cost | $20.7 million | -$5.4 million | -21% | $36.7 million | +$10.6 million | +41% |
| | Annual operating cost per passenger | $0.55 | -$0.06 | -9% | $0.69 | +$0.08 | +13% |
| | Annual operating cost per new passenger relative to base case | $1.02 | +$0.00 | +0.4% | $1.01 | -$0.00 | -0.1% |

**Table C-8: Effects of changing operating hours**

| | | Reduced Operating Hours | | | Increased Operating Hours | | |
|---|---|---|---|---|---|---|---|
| | | Result | Absolute Difference | % Difference | Result | Absolute Difference | % Difference |
| **LRT** | Total ridership | 38.1 million | -900,000 | -2% | 40.0 million | +900,000 | +2% |
| | New ridership relative to base case | 21.0 million | -900,000 | -4% | 22.9 million | +900,000 | +4% |
| | Annual vehicle hours of revenue service | 264,000 | -10,600 | -4% | 285,200 | +10,600 | +4% |
| | Capital cost per new passenger | $26 to 38 | +($1 to2) | +4% | $24 to 35 | -($1 to 2) | -4% |

| | | Reduced Operating Hours | | | Increased Operating Hours | | |
|---|---|---|---|---|---|---|---|
| | | **Result** | **Absolute Difference** | **% Difference** | **Result** | **Absolute Difference** | **% Difference** |
| | Total annual operating cost | $61 million | -$2.4 million | -4% | $65.9 million | +$2.4 million | +4% |
| | Annual operating cost per passenger | $1.60 | -$0.02 | -2% | $1.65 | +$0.02 | +1% |
| | Annual operating cost per new passenger relative to base | $2.90 | +$0.01 | -0.4% | $2.88 | -$0.01 | -0.4% |
| **SkyTrain** | Total ridership | 42.1 million | -800,000 | -2% | 43.6 million | +800,000 | +2% |
| | New ridership relative to base case | 25.0 million | -800,000 | -3% | 26.5 million | +800,000 | +3% |
| | Annual vehicle hours of revenue service | 283,800 | -9,400 | -3% | 302,600 | +9,400 | +3% |
| | Capital cost per new passenger | $88 to 112 | +$3 | +3% | $82 to 105 | -$3 | -3% |
| | Total annual operating cost | $25.3 million | -$800,000 | -3% | $63.4 million | +$800,000 | +3% |
| | Annual operating cost per passenger | $0.60 | -$0.01 | -1% | $0.62 | +$0.01 | +2% |
| | Annual operating cost per new passenger relative to base case | $1.01 | $0.00 | 0% | $1.01 | $0.00 | 0% |

As the above two tables have indicated, increasing or reducing the service frequency by one minute throughout all hours of the week will have a more significant effect than extending or reducing the service by one hour each day. Increasing the service frequency also appears to have a stronger effect than reducing the frequency.

Interestingly enough, the financial burden of enhancing the service levels (frequency or service hours) of the LRT option seems to outweigh the financial benefits of having a higher ridership. In contrast, the new ridership gained by the SkyTrain option due to service level enhancements would more than offset the increased operating cost. This difference is attributed to the higher operating cost per service hour for the LRT option, as a driver is required to operate the trains.

It is important to note that in the full UBC Line sensitivity analysis, the actual capital cost should also be adjusted, as more or less vehicles may be required to meet these service level enhancements or reductions. The change in capital cost has been left out of this sensitivity analysis, as the cost and number of vehicles required are unknown at this time.

***Financial Parameters***

*Increased Construction Costs*

From the experience of the Canada Line as well as many other infrastructure projects that have been recently built in Metro Vancouver, we know that due to the 2010 Olympic Games construction costs have turned out to be much higher than initially calculated. If construction costs keep increasing due to other factors such as a higher demand for housing and infrastructure, then the cost of building the LRT and SkyTrain options could be higher than assumed in this case study.

***Design Criteria***

*Change to Cut-and-Cover Construction Method*

In the UBC Line case study, it is assumed the SkyTrain option would be built using the bored-tunneling technique. If, however, further planning results in changing it to a cut-and-cover technique, as was done for the Canada Line, then the impact to the community during the construction phase would increase considerably. The volume of concrete used and the amount of pollution produced from construction equipment would also increase, as the tunnels would need to be covered by a new layer of concrete. On the other hand, the capital cost would likely be reduced.

## Summary

This sensitivity analysis has shown that changes to trip making and travel preferences along the Corridor and within the station study areas can have a significant effect on the evaluation outcomes. The same can be said for changing the service levels, financial parameters, and design variables. Particularly influential parameters are: vehicle operating costs; the retention or reduction of the base bus service; bus service frequency; construction cost; and the construction method used for the SkyTrain line. Table C-9 summarizes those results that show significant changes when these parameters are varied. Those that are especially sensitive to changes to the key parameters are bolded in black.

**Table C-9: Summary of significant sensitivity analysis results**

| | | LRT | SkyTrain |
|---|---|---|---|
| **Trip Making and Travel Preference** | Increasing vehicle operating costs | • Total and new ridership<br>• Capital cost per new passenger relative to base case<br>• Operating cost per passenger and per new passenger relative to base case<br>• Gross annual operating revenue<br>• **Cost of traffic services**<br>• **Congestion cost savings relative to base case** | • Total and new ridership<br>• Capital cost per new passenger relative to base case<br>• Operating cost per passenger and per new passenger relative to base case<br>• Gross annual operating revenue<br>• **Cost of traffic services**<br>• **Congestion cost savings relative to base case** |
| | Walking/cycling trips replacing transit trips | • Cost of traffic services<br>• Congestion cost savings relative to base case | • Cost of traffic services<br>• Congestion cost savings relative to base case |
| **Service Levels** | Maintaining base bus service with rapid transit | • **Total and new ridership**<br>• **Capital cost per new passenger relative to base case**<br>• **Operating cost per passenger and per new passenger relative to base case**<br>• **Gross annual operating revenue**<br>• **Cost of traffic services**<br>• **Congestion cost savings** | • **Total and new ridership**<br>• **Capital cost per new passenger relative to base case**<br>• **Operating cost per passenger and per new passenger relative to base case**<br>• **Gross annual operating revenue**<br>• **Cost of traffic services**<br>• **Congestion cost savings** |
| | Increasing or reducing service frequency | • **Total and new ridership**<br>• **Annual vehicle hours of revenue service**<br>• **Capital cost per new passenger relative to base case**<br>• **Total annual operating cost**<br>• **Annual operating cost per passenger**<br>• Annual operating cost per new passenger relative to base case | • **Total and new ridership**<br>• **Annual vehicle hours of revenue service**<br>• **Capital cost per new passenger relative to base case**<br>• **Total annual operating cost**<br>• **Annual operating cost per passenger**<br>• Annual operating cost per new passenger relative to base case |

| | | LRT | SkyTrain |
|---|---|---|---|
| | Increasing or reducing operating hours | • Total and new ridership<br>• Annual vehicle hours of revenue service<br>• Capital cost per new passenger relative to base case<br>• Total annual operating cost<br>• Annual operating cost per passenger | • Total and new ridership<br>• Annual vehicle hours of revenue service<br>• Capital cost per new passenger relative to base case<br>• Total annual operating cost<br>• Annual operating cost per passenger |
| **Financial Parameters** | Increasing construction costs | • **Capital cost** | • **Capital cost** |
| **Design Criteria** | Changing construction method for SkyTrain to cut-and-cover | | • **Effects of construction on community**<br>• **Volume of concrete used and air pollution from construction**<br>• **Capital cost** |