

# A Web-based Transit Technology Selection Model

by

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## **AUTHOR'S DECLARATION**

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

## Abstract

There are many cities in North America planning to upgrade or implement public transportation infrastructure with the goals of increasing transit ridership and promoting transit-oriented development. The most commonly considered transit systems in mid-sized cities are bus rapid transit (BRT) and light rail transit (LRT). Planners and engineers in these cities often debate on which of these modes offer the more appropriate technology to meet the cities' transit requirements. From a transportation engineering perspective, the goal of technology selection should be to choose the mode that has the best set of attributes – investment cost, operating cost, environmental and land use impacts – for the city and / or region.

This thesis presents the development of an easy-to-use and accessible model (available via website) that assists in the technology selection process, considering investment costs, operating costs and environmental impacts. The objectives of this model include: finding annual costs for the transit modes being evaluated, finding the most appropriate transit mode for a specific scenario, finding the demand at which both transit modes have the same annual costs, testing the sensitivity that outputs have to inputs, finding annual emissions produced for both modes, and showing results that are visual and easy to understand.

The model developed in this thesis is applicable mainly in mid-sized cities, which are interested in implementing new, or to improve existing transit systems into, rapid transit systems, like LRT and BRT, but the methods could be easily extended to apply it to other technologies as well. The model was applied to four cases to determine which mode would be more appropriate in these scenarios. The cases that will be studied include: Region of Waterloo in Ontario; Victoria, British Columbia; Cleveland, Ohio; and Mexico City. The model used the data pertaining to these regions for future systems currently under study and/or development, as Waterloo and Victoria, and existing systems, as Cleveland and Mexico City, to compare costs and emissions of BRT and LRT and determine which system would or would've been more appropriate in these different locations under specific parameters.

The results of the analysis made to these four case studies showed how the model can be used in the technology selection process. For these cases it was found that, for the Region of Waterloo and Victoria, LRT would be the less expensive mode in an annual basis, while, for Cleveland and Mexico City, BRT would be the less expensive mode. The break-even point analysis concluded with three main outcomes: for the Region of Waterloo this point would be 1200 passengers/hour and for Victoria it would be 1500 passengers/hour, which is less than the projected ridership for both cases; and for the other two cases (Cleveland and Mexico City) this point was not found for the stated scenario. The findings in the emissions module were the following: for the Region of Waterloo and Victoria: LRT would be the cleaner mode for all emissions; and for Cleveland: LRT would be the cleaner mode when considering NO<sub>x</sub>, but BRT would be the cleaner mode for SO<sub>2</sub> and CO<sub>2</sub>. Future research can be conducted in adding more technologies into the comparison made in the model making the model functional for smaller and/or larger cities. Further investigation can also be applied in the emissions module creating a larger database to make this module capable of obtaining results in a global scale.

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Last, but definitely not least, I would like to thank God, because without Him this would not have been possible.

## **Dedication**

This is dedicated to my rock, my inspiration, my best friend, the reason this has been possible, my mom.

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# Chapter 1

## Introduction

There are many cities in North America planning to upgrade or implement public transportation infrastructure with the goals of increasing transit ridership and promoting transit-oriented development. In larger cities, as San Juan, Toronto or New York, metro systems are typically warranted due to the very large passenger demand. In small cities, such as Kingston, Guelph or Peterborough, the opportunity to upgrade or provide additional conventional bus services are being reviewed to effectively meet passenger demand.

In many mid-sized cities, the most commonly considered transit systems are bus rapid transit (BRT) and Light Rail Transit (LRT). Planners and engineers in these cities often debate which mode offers the more appropriate technology to meet the cities' transit requirements. Promoters of LRT systems describe greater labor and energy productivity, positive environmental characteristics and greater influence on land use. BRT supporters note lower investment costs and greater flexibility of these systems.

From a transportation engineering perspective, the goal of technology selection should be to choose the mode that has the best set of attributes – investment cost, operating cost, environmental and land use impacts – for the city and / or region. As noted above, there exist levels of demand for which the reduced operating costs of rail systems offset their higher investment costs. Similarly, there are other cities in which the demand is so low that the higher investment costs can never be recovered.

The goals of this thesis are to develop and apply a quantitative model that assists in the technology selection process, considering investment costs, operating costs and environmental impacts. The model computes life cycle costs for two technologies based upon user-specified system and operating data. Rather than simply computing the breakeven point – i.e. the level of demand for which one technology has lower life cycle costs – the model computes ranges of

demand for which one mode has a clear advantage. This allows the analyst to use some judgment when the breakeven demand is very near to the predicted demand. The model also uses spatial information on energy sources to generate estimates of commonly produced airborne pollutants during the analysis period. Finally, the model allows the user to test the sensitivity of technology selection to operating cost parameters particularly maintenance, labor and energy costs.

## **1.1 Motivation**

Choosing a transit mode for a specific system consists of a series of steps that consider different factors, including the economic and environmental aspects. Uncertainty still remains when comparing different modes. This debate of whether to develop a rail based or bus transit has been ongoing for many years. The cost effectiveness of transit systems, especially BRT and LRT, is still being questioned.

The main reason for these debates is the lack of conclusive information in the matter. Just as consumers need and want detailed information about the products they are about to purchase, decision makers need accurate and broad information about transportation and planning decisions and/or alternatives. (Litman, 2009) Because of this, the decision making process needs to be as detailed as possible when comparing the alternatives available. All factors need to be taken into consideration to make a fair comparison.

Trying to minimize this uncertainty, this thesis develops an easy-to-use model that achieves a thorough comparison of these two systems, comparing costs and emissions. The inputs required to run the model are all the system characteristics; from these the annual cost for each mode is calculated. The costs for both modes are shown in detail. Comparison of emitted pollutants is also shown for three specific compounds. Values are shown numerically and graphically for better understanding.

## 1.2 Goals and Objectives

The main goal of this research is to develop an easy-to-use and accessible model (available via website) to help decision makers choose the most appropriate transit technology that will meet their requirements. The motivation for developing an on-line model is two-fold. The most basic motivation is to make the model as widely available as possible and to test the model's functionality under a wide range of inputs. For example, the model may be used by analysts in Mexico where energy and labor prices tend to be significantly lower than in North America, but where uncertainty may be higher. A second motivation for a web-based model is that the analyst's location can be determined based on the IP address when accessing the site. The location information can then be used to populate the model with default values for operating costs and parameters that are derived from local data. While not part of this thesis, this extension to the model may hold great promise.

The model allows planners and engineers to determine the relative domains of demand for which rail and bus are more cost effective. It also gives a detailed cost estimation, showing the different cost factors, which helps assess the sensitivity of the inputs to each of these costs.

The objectives of this thesis include:

- The development of an easy-to-use interface for entering system data and operating parameters
- The creation of web-based code (written in JavaScript) that calculates life cycle costs for the different transit modes evaluated and presents the information in a variety of formats
- The ability to find the economic breakeven point – i.e. the demand at which the two systems have equal life cycle costs;
- The determination of appropriate ranges for demand under which a transit mode is more appropriate for a given set of data
- The capacity to analyze the sensitivity of specific inputs to the economic factors of the system
- The calculation of the annual emissions produced for specific pollutants for each mode
- The presentation of detailed results, numerically and graphically, for better understanding and analysis

The main objective of this thesis is to determine the conditions under which a particular transit mode is more effective. A model is developed in this research to achieve these objectives.

## **1.3 Thesis organization**

The remainder of the thesis is organized as follows. Chapter 2 presents the literature reviewed before developing the model. Chapter 3 discusses the methodology followed to develop the model for this research. Chapter 4 introduces four case studies – cities where LRT and BRT are being considered or one has been implemented – and applies the model to data from these cities. In Chapter 5, the results obtained from the model’s applications to the case examples are discussed. Chapter 6 provides the conclusion achieved by this research and possible future research.



# Chapter 2

## Literature Review

The selection of a transit mode creates many debates in urban transportation discussions. When choosing a transit mode, especially when choosing between bus and rail, there are many points of contention because both of these systems can provide a similar service for medium-sized cities and both require similar Right of Way (RoW). (Hsu, 2005) Factors that are influential in the decision making process behind technology selection include demand, cost and emissions; these create a wide range of alternatives within different transit modes.

In order to make a fair comparison between different transit modes, LRT and BRT in this research, all characteristics regarding the systems need to be taken into consideration. In these types of comparisons, the main emphasis is typically given to their differences in costs. Even though the difference of emissions between modes is also compared, it is not as easy to quantify as costs and, as a result often may be disregarded. However, this is of critical importance.

The main objective of this thesis is to determine the conditions under which a particular transit mode is more cost-effective. To achieve this objective a model is developed for this research. This model determines the total annual costs of two different modes, LRT and BRT (though it can be extended to more modes for future research), and finds the economic break-even point, which is where both systems have the same life-cycle costs. Pollutants emitted are also compared within the model.

This chapter reviews the literature which informed the development of the model. A brief examination of the literature on decision-making processes in transit is made. Then a description of the modes studied is given, and different points of view about both transit modes from various articles are discussed. This chapter also includes literature on demand, costs and their factors, to detail their importance within this research. Finally, literature on cost estimating methods and emissions comparisons are also reviewed.

## 2.1 Transit Mode Selection Process

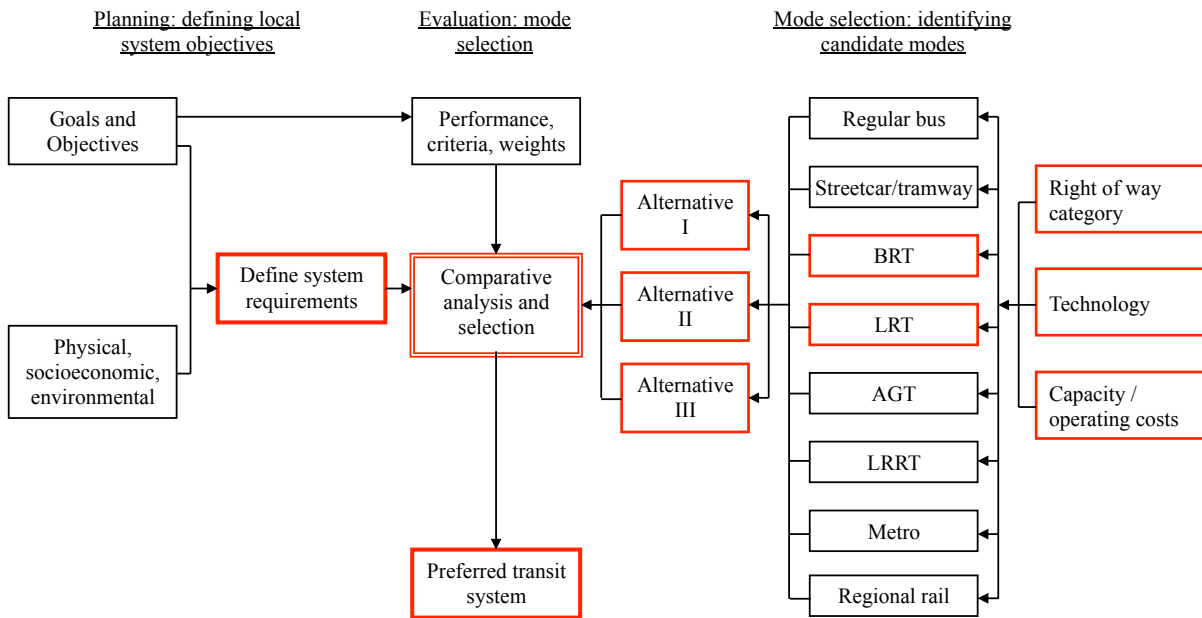
The selection of transit mode for a city is a complicated task. There are several steps behind this process that should be followed in order to make an effective evaluation. This section describes briefly how this process is commonly made and which methods should be followed to increase the likelihood of making the right choice.

Vuchic (2005) states that the evaluation of transit modes should utilize the same basic methods as the described evaluation of all public projects: “All benefits and costs of each transit project must be estimated to find its worth, which must then be compared with the corresponding worths of alternative modes or systems in the planning process.” Evaluation of modes should be made as an analysis of supply and demand. Demand is defined as the need for travel and area to be served; supply is the transit modes or alternatives offered.

The steps involved in this decision include:

- Planning (when goals and objectives are defined),
- Evaluation (where the comparative analysis takes place) and,
- Mode selection (when candidate modes are identified based on combinations of RoW, technology, capacities and costs).

Performance characteristics of different potential systems are compared to the requirements defined during the earlier steps. During the mode selection procedure the main quantitative comparison is between costs and potential passenger attraction. (Vuchic, 2005) Figure 2.1 shows a diagram by Vuchic (2005) that illustrates the process and the steps followed when selecting a transit mode.



Based on Figure 11.6 in Vuchic (2005)

**Figure 2.1 Mode Selection Process by Vuchic (2005)**

During the comparative analysis, it is difficult to quantify the exact differences in cost between BRT and LRT since there are a great variety of systems with different characteristics. Because of these differences, there is significant variation in capital costs even within the same type of transit. When a comparison is made among different modes in respect to their capital cost it is very important to be consistent about the costs reported, and all the components that affect these costs should be examined and compared. The differences in operating costs and ridership levels are also caused by the large variety of systems. These costs can also be affected by size and capacity of the vehicles used. (Zhang, 2009; Kuhn, 2002) Table 2.1 shows different types of transit unit (TU) sizes and capacities that can be offered by both systems – a transit unit is a single or combination of vehicles operated with a single driver.

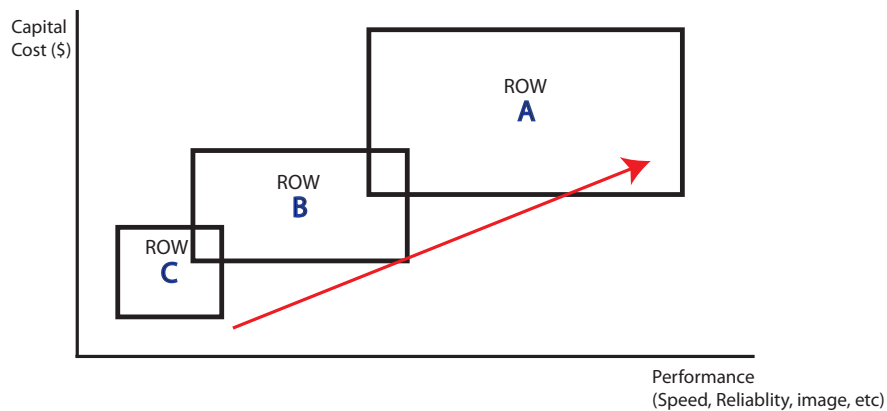
**Table 2.1 Different Vehicle Characteristics for BRT and LRT**

Service type	TU size [veh/TU]	Vehicle Capacity [spaces/veh]	Capacity/TU
BRT North America	1	120	120
BRT Developing Countries	1	180	180
LRT	2-3	180	360 - 540

Source: Vuchic (2005)

There are features of each mode that must be considered in order to make a reasonable decision when comparing different transit modes. These include, but are not limited to: length of alignment, fleet size, number of stations, scheduling, and frequency, among others. (Tirachini et al., 2010) Exclusive right of way is an important factor of its effectiveness that should be considered especially in rapid transit systems; it also is what causes high construction costs. (Kuhn, 2002)

Right of Way (RoW) can be defined as “the land on which the transit system operates.” There are three categories of RoW: A, B and C. Category A is defined as fully separated way, without neither intersections nor legal access to other vehicles. This category is often implemented using tunnels or elevated structures. Category B is defined as transit that is longitudinally separated from other traffic, but is affected by intersections. Category C is defined as transit operating in mixed traffic. (Casello et al., 2009) RoW is the main factor that influences capital costs; as RoW increases, costs and performance – the level of service offered by the system – increases as well. This is shown in Figure 2.2. See Table 2.3 for the influence of RoW on capital costs.



**Figure 2.2 Right of Way effect on capital costs and performance**

Even though in the decision making process importance is typically given to cost, this is not the only factor that is significant. Other factors such as emissions, Central Business District (CBD) revitalization and passenger support/attraction, among others, should also be considered. There are many characteristics of transit systems that are complex and cannot be given a quantitative value. These, then, are more difficult to consider when evaluating. (Greenberg, 2005; Vuchic, 2005)

“No single form of transit will fit all market needs of a community.” Each technology can be efficient when it is built to serve the right place and the right market. (Zhang, 2009) The question then remains, which mode is more efficient for a specific scenario?

**Table 2.2 Summary Table of Variables**

Variable	Values	Impacts
Right of way	Fully exclusive, longitudinally separated, mixed traffic	Increasing capital costs but improved performance with degrees of separation
Technology <ul style="list-style-type: none"> <li>• Propulsion</li> <li>• Guidance</li> </ul>	Diesel, electric <ul style="list-style-type: none"> <li>• Rail vs. Steered</li> <li>• Manual vs. Signals</li> </ul>	Diesel requires less infrastructure, lower capital costs; electric produces less emissions
Capacity	See Table 2.1	Rail transit has larger capacity that reduces operating costs if demand warrants
Land use influence	Density: population and / or employment per unit of area	Typically higher capital investment produces larger changes in land use.

## 2.2 Description of Modes

This section provides a concise description and definition of the modes analyzed in this research. Additionally, the typical arguments made by supporters of each mode are discussed briefly in this section.

### 2.2.1 BRT

The American Public Transportation Association (APTA) (2012) defines BRT as: “A type of limited stop service. It combines the quality of rail transit and the flexibility of buses. BRTs can operate on exclusive transitways, high-occupancy vehicle lanes, expressways, or ordinary streets. A BRT line combines ITS technology, priority for transit, rapid and convenient fare collection, and integration with a land use policy in order to substantially upgrade bus system performance.”

BRT is commonly defined as a bus-based rapid transit that has exclusive right of way and it’s very similar to LRT. BRT, in simple words, is a system that consists of busways using high capacity buses. A busway typically consists of a two-way roadway on a separated right of way.

(Kittleson and Associates, 2007; Kühn, 2002) Main features for BRT, according to Kittleson and Associates (2007), include: exclusive lanes, accessible and attractive stations and vehicles, efficient fare collection, ITS applications, and frequent service.

Some main characteristics of BRT include: diesel powered, manually guided, fully separated RoW and very little infrastructure.

Recently implemented BRT systems in North America include: VIVA in York Region, Ontario; Züm in Brampton, Ontario; Metrobús in Mexico City, Mexico; Silver Line, in Boston, Massachusetts; and HealthLine in Cleveland, Ohio.

### **2.2.2 LRT**

The Transportation Research Board (TRB) (1989) defines LRT as: “A metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways, or occasionally, in streets and to board and discharge passengers at track or car floor level.”

APTA (2012) defines LRT as: “Lightweight passenger rail cars operating singly (or in short, usually two-car trains) on fixed rails in ROW that is not separated from other traffic for much of the way. Light Rail Vehicles are driven electrically with power being drawn from an overhead electric line via a trolley or a pantograph.”

Rail systems are able to avoid congestion but in order to be able to do this properly exclusive right of way is needed. High construction costs relative to bus is because of infrastructure - rails, signals, electrification, etc. (Kuhn, 2002)

Recently implemented LRT systems in North America include: O-Train in Ottawa, ON; LYNX Rapid Transit Services in Charlotte, and NC; and METRORail in Houston, TX.

### 2.2.3 Debate between modes

Selecting the most appropriate transit mode for a city can initiate many debates. This is mainly caused by the uncertainty and lack of conclusive information in the matter. (Kühn, 2002) The most common debates emerge when the decision to be made is whether the mode should be rail or bus. Many developments in both systems generate discussions on comparative advantages one system has over the other. Typical points of contention include whether a system would be less expensive, or more reliable, among other characteristics. It can be assumed that the government and media attention goes primarily to infrastructure costs and demand levels, and the main difference between these two modes lies in operating costs and capital costs. (Hensher et al., 2008; Zhang, 2009)

BRT is seen, by many, as a lower-cost alternative to LRT. Even though capital costs for LRT are, generally, higher than for BRT, it is not always the same situation when comparing operating costs. While BRT can have lower capital costs, it is more labor-intensive. LRT is the opposite, it can have lower operating costs but it is more capital-intensive. (Brunn, 2005; Kühn, 2002; Hsu 2005)

Table 2.3 shows the advantages both systems have as stated by their supporters. Accentuated in bold are the main characteristics studied in this research.

**Table 2.3 Advantages of BRT and LRT as stated by their supporters**

BRT	LRT
<b>Low cost (infrastructure)</b>	Attract development – increasing density
Flexibility – Adaptable to different demands and patterns	Better quality of service – higher speeds, comfort and convenience
More lines for a fixed amount of money	More attractive – decreasing private auto ownership
Serve more destinations in dispersed regions	<b>More labor productivity</b>
	Less noise
	<b>More diverse energy sources; lower pollution in urban centers</b>

(Henry et al., 2006; Litman, 2006; Puchalsky, 2005)



LRT critics suggest that it is expensive to build and operate and that its supporters oversell it. Even though LRT is often criticized for its high construction costs, when building new infrastructure for BRT costs can be as high as LRT's. LRT capital costs increase as right of way exclusivity increases, but it is worth mentioning that for any system as right of way increases capital costs increase as well, as shown previously Figure 2.2. (Henry et al., 2006; Greenberg, 2005)

While cost is the main difference between these two modes, or is the main factor considered in their comparison, there are other important factors that need to be taken into consideration. Some of these factors include: capacity, comfort and reliability. Rail advocates' main defense is that comparing only costs makes the comparison incomplete and flawed. (Zhang, 2009)

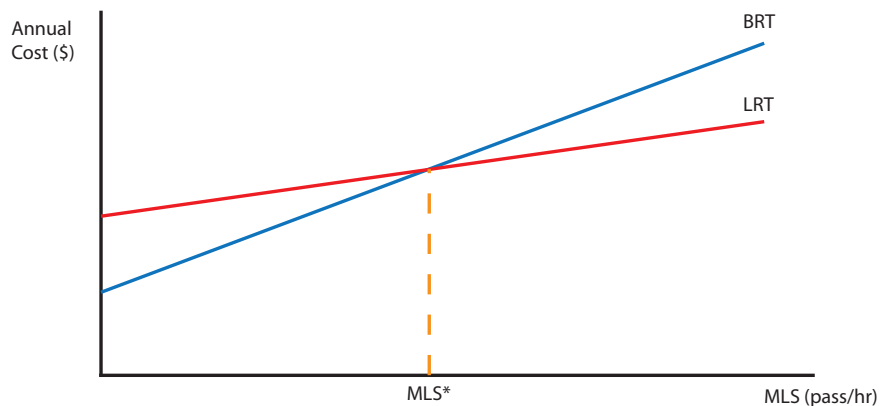
Furthermore, another important debate that emerges is when comparing energy consumption and pollution emissions. Some might say that LRT is not polluting because it does not run on petrol or diesel power, and that, because of this, it is often inferred that BRT emits more pollutants than LRT. (Kuhn, 2002; Puchalsky, 2005)

One of the advantages that BRT supporters promote is that it can start to operate in phases; the construction of the system doesn't have to be finished entirely for it to begin its operations. Another advantage for BRT is that it can be built within existing roadways. (Kuhn, 2006; Henry et al., 2006) The main advantages for LRT supporters that LRT has are higher commercial speeds, higher capacities (LRT has higher theoretical capacity than BRT – more passengers per trip – usually from 3,000 to 20,000 passengers per hour per direction), it is more attractive to car users, and it has a stronger image. It is also effective in reducing traffic and parking problems. (Kuhn, 2002; Henry et al., 2006; Hsu, 2005)

Other researchers have attempted to validate many of the assertions presented here by conducting “before and after” studies in areas where either technology – LRT or BRT – has been implemented. Typically, these studies compare projected ridership versus realized ridership; but this method has flaws. There are many variables that influence ridership besides technology, as fuel prices, city growth, economic shift, etc. Further, the influence of transit

investment on land markets is equally if not more difficult to measure empirically. Essentially, developing causality between transit investments and changes in travel or land use is very difficult.

The goals of this research are to develop a model that completes two tasks: define a break-even point in the deterministic case but also allows for testing of sensitivity to inputs. The model determines a break-even point that determines the maximum load section (MLS), point along line where demand is highest, at which both systems have the same life cycle costs. When there's no clear advantage of one mode over the other, the model lets the analyst then use some judgment when the predicted demand is near this point. The analysis is shown conceptually in Figure 2.3, where  $MLS^*$ , is the break-even point for demand. Sensitivity to inputs becomes most important for values of the MLS nearest to this  $MLS^*$  break-even point. The BRT line, as seen in Figure 2.3, has a higher slope due to lower capital costs, which affect only the origin of the line, while having lower labor and energy productivity which create higher annual costs.



**Figure 2.3 Break-even point concept**

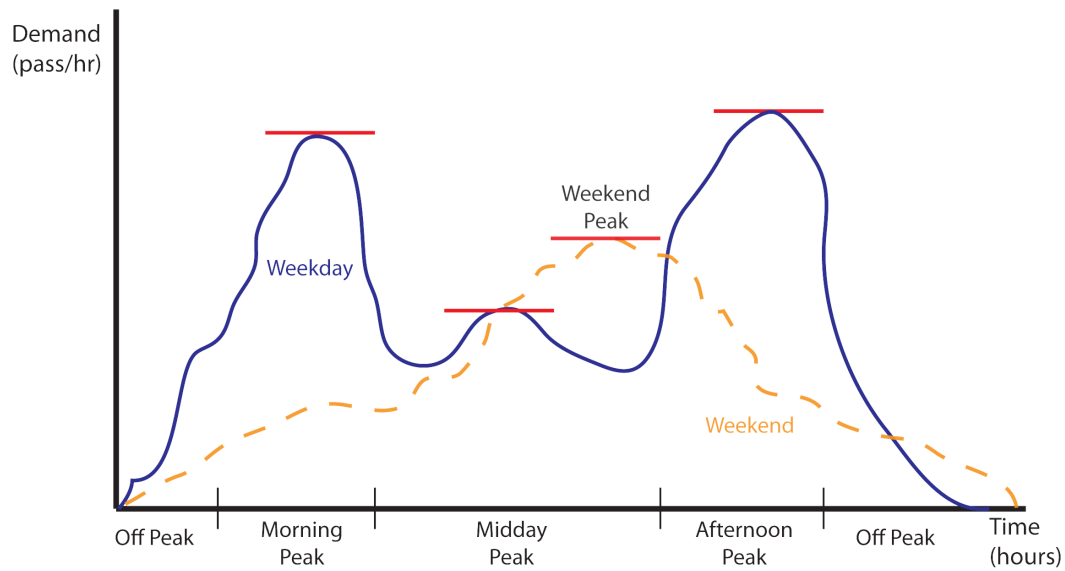
## 2.3 Demand

Demand is one of the main factors that influence decisions regarding the selection of a transit mode and, as such, demand is one of the main factors of the model developed for this research,

along with costs. Demand has a direct influence on the system's cost because larger demands represent more vehicles, more operators, and more offered capacity. As demand increases costs increase as well.

Demand is the volume of passengers utilizing the system, usually expressed in passenger volume (passengers per hour). Demand should be the basic component that dictates the type of transit service. The maximum passenger volume is found in the Maximum Load Section (MLS). (Vuchic, 2005) Passenger demand determines the cost and reliability of the different modes and ROWs that should be offered; it also determines the cost because it defines the capacity that needs to be provided. (Casello et al., 2009)

Many factors influence demand such as: city size, population, population density, location, and fare. Demand also varies as a function of time, depending on time of the year, time of the week, and time of the day. Passenger demand on weekends is lower when compared to workdays where commuters use transit to and from work. This is also consistent for time of day. Hourly variations of demand are more noticeable on workdays. (Vuchic, 2005) This can be seen in Figure 2.4. This figure shows that there are two high peaks - the morning and afternoon "rush hours" - on a regular workday. This happens because at these times commuters travel to and from work. In these peaks is where the MLS is found. The values in this graph are also used to determine demand levels, which dictate the capacity that should be offered at different times of the day. Non-peak demand values are typically expressed a specified percentage of the MLS during peak hours. This is discussed further in the next sections.



**Figure 2.4 Demand as a function of time**

Figure 2.5 shows the typical behavior of demand among a line during a specific time, typically peak hour. The vertical axis represents the cumulative demand and the horizontal axis is the distance traveled along the line. The change at each station is a result of the difference in boardings and alightings. For example, at station B the number of boardings is higher than the alightings, while in station E there are more alightings than boardings. This figure also shows the difference of this MLS during different times of day. This shows that, for this example, the peak MLS occurs in section D-E of the line, while off-peak MLS occurs in section E-F. As shown in this figure, off-peak capacity is a percentage of the peak capacity.

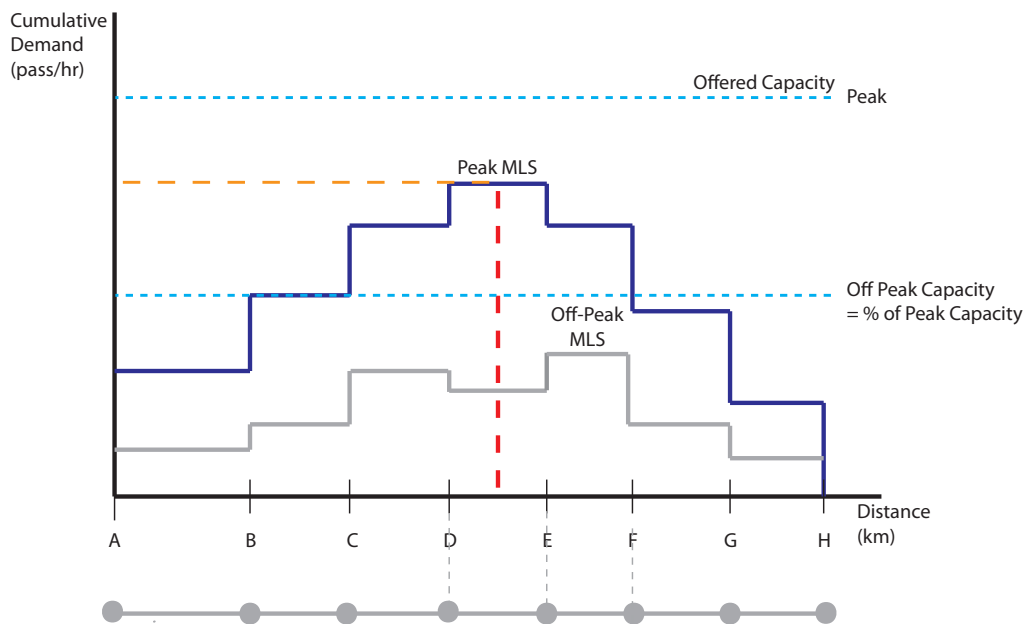


Figure 2.5 Typical behavior of demand along a line

### 2.3.1 Demand estimating methods

There are different methods of estimating transit ridership/demand for a system. Two main methods will be discussed and briefly reviewed in this section. One method commonly used creates a likelihood model by studying the system's surroundings taking into consideration factors as: number of households, income levels, auto ownership, household composition (age and occupation) and land use. From these data, a percentage is obtained of households that are candidate transit users are identified. This percentage is then applied to the number of trips generated in this area. (Casello et al., 2009)

The second method utilizes two concepts – generalized cost and logit model. This methodology is based on the competitiveness of a service relative to other modes available. The main assumption of this method is that travelers will choose the mode that will help minimize their total cost. This model considers times, fares and other out of pocket expenses and the value of time. (Vuchic, 2005; Ortuzar et al., 2011)

$$P(A_i) = \frac{e^{u_i}}{\sum e^{u_i}} \quad \text{Eq. 2.1}$$

Equation 2.1 shows the logit model formulation, where  $P$  expresses the probability for choosing mode  $A$  of an  $i$  amount of modes and  $u$  represents the utility function, which determines the preference of an individual towards that specific option.

The estimated demand is what's used to estimate the annualized operating costs and vehicle capital costs per mode. This estimation helps the analyst have a good projection on how much capacity needs to be offered, hence how much the operation and vehicles needed will cost.

## **2.4 Cost**

Cost is the other principal factor considered when deciding what type of transit will be built in a city or region. The main costs discussed in this section are capital and operating costs. This section defines these costs, reviews all their components and gives typical values for both BRT and LRT. For capital costs, data are presented on total cost/km; costs for vehicles; and costs for stations. For operating costs, typical values of wages are presented, as well as energy and maintenance rates.

### **2.4.1 Capital Costs**

Capital cost is a one-time investment cost for a project. Transit capital costs include infrastructure construction costs, vehicle costs and station construction costs. Both systems considered in this thesis have very different costs, and these will be discussed next.

BRT infrastructure costs per kilometer vary greatly, from a \$53.2 M/km in Boston to \$0.35 M/km in Taipei (2006 US\$). The main infrastructure cost factors are: 1) construction costs, including labor, year of construction, funding source, number and size of stations, and 2) the system's RoW, considering here intersections and signalization. (Hensher et al., 2008) Table 2.4 shows the average values for infrastructure construction cost for BRT.

**Table 2.4 Average values for infrastructure construction cost for BRT**

Busway Type	Cost/Lane-Mile (millions USD)
At Grade	\$6.5 to \$10.2
Aerial	\$12 to \$30
Below Grade	\$60 to \$105

Source: Kittleson and Associates, 2007

Costs included in busway construction are land acquisition, construction and engineering. Infrastructure costs should be carefully estimated because they vary by different factors as location, type, and design features, among others. (Kittleson and Associates, 2007)

LRT's basic costs components include: infrastructure, rolling stock, fleet, fixed equipment, operating and maintenance centers, electric power supply, signals, communication facilities, etc. (Hsu, 2005) LRT cost averages around \$22 Million per kilometer; it ranges from to \$12.4 to \$118.8 Million per mile. (Hess et al., 2005)

As it was mentioned earlier, another main component of capital costs for all technologies is vehicle cost. This factor depends on the maximum vehicle service for the system, which therefore depends on the capacity offered. There are many different types of vehicles for both systems. Vehicle costs for both modes vary greatly depending on vehicle models. Typical values for these are given in Table 2.5.

**Table 2.5 Typical Vehicle Cost**

Type of Vehicle	Cost of Vehicle
Standard 35' (1)	\$276,000
Standard 40' (1)	\$341,000
Trolley Bus (2)	\$850,000
Articulated Bus (1)	\$534,000
Articulated Trolley Bus (2)	\$1,800,000
Double Decker (2)	\$600,000
Electric Streetcar (2)	\$1,800,000
Tram (2)	\$3,000,000
Light Rail Vehicle (2)	\$4,000,000

Source: (1) Casello et al., 2009

(2) Calgary Transit, 2002 (Values in CAD 2000)

Station costs ranges from \$50,000 to \$9 Million. Costs for station greatly depend on design, aesthetics, and height, among other factors. Stations usually protect from weather, provide passenger information and amenities, safe and secure access and integration with other modes. It also includes fare collection if it is off-board. (Danaher, 2009)

## 2.4.2 Operating Costs

Operating costs come from daily operations of the system. These include wages (for operators, and other operating employees), fuel and energy costs, maintenance and repair, fare-collection costs, advertising, information and marketing, vehicle licensing and registration, insurance, and administrative expenses. Salaries are the main expense of operating costs. (Vuchic, 2005; Garrett, 2004) Since operator wage is the main factor of operating costs it is fair to say that these costs have a large variation depending greatly on operating hours and geographic location.

Labor costs can vary greatly depending on geographic location, as already mentioned. Typical values for operator wages in US and Canada are around \$26 per hour, and for mechanics around \$30 per hour, approximately. (CUTA, 2011) Table 2.6 shows some top wages for operators in Ontario, and Table 2.7 shows average wage rates for other countries. Wages for LRT might be higher than those for bus operators, but this doesn't have a noticeable effect on the total operating costs, because for higher demands one LRT operator can move the same amount of passengers than multiple bus operators, hence labor productivity for LRT is higher.

**Table 2.6 Average wages for operators**

City	Wage Rates (\$/hr)
Ottawa	\$26.28
Toronto	\$29.43
Waterloo	\$26.24
Hamilton	\$27.82

Source: CUTA, 2011



**Table 2.7 Average wages for operators**

Country	Wage Rates (\$/hr)
Australia	\$17.67 - \$27.05
United Kingdom	\$11.89 - \$17.68
USA (California)	\$21.08 - \$30.12 (USD) (LRT)
Mexico	\$8 - \$10 (USD)

Source: PayScale, 2013

Energy rates are also mainly dependent on geographic location, but also on the power source.

Table 2.8 shows the average cost of electricity and diesel in different Canadian cities.

**Table 2.8 Energy rates in Canadian cities**

City	Electricity cost (\$/kWh)	Diesel cost (\$/L)
Toronto	0.14	1.29
Calgary	0.10	1.15
Halifax	0.14	1.37

Source: Natural Resources Canada, 2013; Manitoba Hydro, 2012

**Table 2.9 Summary Table of Costs**

Cost component	Typical values	Comparison
Capital cost	Infrastructure BRT: \$15 M/km LRT: \$30 M/km Vehicle BRT: \$0.75 M/veh LRT: \$4.5 M/veh	Rail much higher than bus
Labor costs	\$26/hour	Rail vehicle capacity means labor costs grow more slowly as a function of demand
Energy costs	Diesel: \$0.90 Electricity: \$0.12	Rail lower than bus
Maintenance costs	BRT: \$0.3 /veh-km LRT: \$0.5 /veh-km	Rail higher than bus, main difference due to track maintenance

## 2.5 Cost Estimating Method

There have been several studies and models finding values to try and achieve a fair comparison between these different transit modes. This section reviews these studies.

Allport (1981) developed cost models to compare costs of operation, maintenance and administration of bus, light rail and metro systems. He applied these models using comparable data studying different demand levels. He found that by comparing modes considering user costs in the analysis then bus extends towards a higher demand of passengers, while when considering only operating costs then bus is cheapest for low demands and light rail is cheapest in the middle demand range.

Brunn (2005) developed a parametric cost model that compares the operating costs between BRT and LRT. In his findings, LRT dominates over BRT, sometimes, because of its passenger capacity. In Brunn's model when the maximum load section (MLS) is less than 1600 passengers per hour BRT is in favor, while when the MLS is above 2000, BRT headways become too short, hence it becomes ineffective, inefficient and more expensive to operate. He also found that both LRT and BRT systems have typically lower operating cost per passenger-km during base periods compared to regular buses. When more service is needed, for example in peak hours, then BRT is more expensive to operate than LRT. Brunn's model achieves a comparison with a similar concept as this research. The main difference is that this parametric cost model does not consider capital costs. Capital costs make a significant difference in overall costs and should be considered when evaluating different transit modes.

Tirachini et al. (2010) developed three optimization models in which different transit modes are compared to find under what circumstances each would be the preferred mode. They study the optimal operation of a transit line considering both fixed and elastic demands. With these models, the authors concluded that if operator costs are greater for rail than for buses, and stations are separated equally or greater than in bus systems, a necessary condition for rail to be superior is to be faster. The advantage for rail in terms of operating costs varies as a function of difference in speed. In this model conventional buses dominate for low demand,

BRT for higher demands, considering both operating costs and user costs. Light Rail and Heavy Rail can outperform BRT in higher demands because they can achieve even higher speeds. This research concludes that the only possible advantage of rail is operating speed. The faster the operating speed, the lower the operating costs. Tirachini et al.'s model takes into account both user and operator's costs.

Hsu (2005) created a capacity-based cost model called LBCostor for LRT and BRT systems in her dissertation by examining the factors that impact capacity and cost and then developing a cost model. This model considers different RoW categories and alignment configurations (exclusivity throughout the alignment) to estimate capacity and costs. She developed a user-friendly computer interface integrated with capacity-based models to achieve this comparison.

The main conclusions of Hsu's dissertation are:

- BRT's costs and capacity depend mainly on RoW configuration;
- LRT's train lengths have a disadvantage because they are restricted to street block and length of platforms;
- LRT would be the more suitable system for higher volumes and longer trips;
- If structures for BRT systems are expensive then BRT is less advantageous – for example if there are elevated or underground structures;
- Considering capital cost per distance, BRT is most of the time half the cost of LRT;
- LRT has higher capital costs but lower operating cost than BRT.

The LBCostor uses capacity instead of demand to execute the comparison between modes. One main difference between the LBCostor and the model developed in this research are the inputs and parameters. The LBCostor doesn't have any cost inputs for the user to determine, these are all estimated within the model. The output for the LBCostor provides capacity outputs and total annual cost outputs, while the model in this research determines total annual cost outputs and emission outputs. Finally, the LBCostor doesn't have any graphical outputs; it shows only numerical values.

One main difference from all these models is that the model developed in this thesis does not make any assumptions about land use. Some of these models make assumptions about land use and density and how this will affect demand (riders per capita) and costs. Another difference is that cost values in the model are affected greatly by the numbers entered in the inputs by the

analyst, there are no main assumptions; the user is the one that creates the scenario for both systems to be compared. The model developed for this thesis is also different from these models because it has the ability to test the output's sensitivity to the inputs.

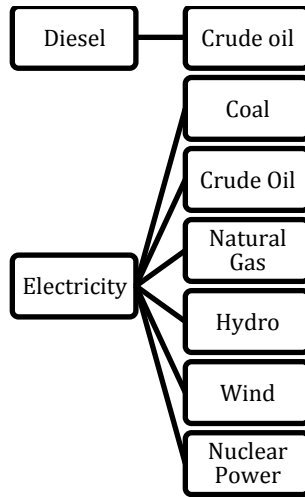
## **2.6 Emissions and Energy Consumption**

As environmental awareness increases, planners and engineers not only focus on the financial aspect of choosing between bus and rail, they are also focusing on the environmental impacts of this decision. An important objective of this research is to calculate the annual emissions produced for specific pollutants by each mode. This is done inside the model developed by using spatial information on energy sources and generating estimates of commonly emitted pollutants. What is important behind this process is to identify how much energy is consumed and how this consumption then converts into emissions. Naturally, emissions are a function of energy source. For example, if electricity for LRT is generated from dirty coal, then the emissions regarding its operations could be more harmful to the environment, than a BRT that uses diesel. This is why geographic location plays a very important role when determining the quantity of pollutants released into the atmosphere.

This section discusses the literature for energy consumption and emissions created by transportation modes. This section also shows typical values for energy consumption and emissions for transportation.

### **2.6.1 Energy Source**

Knowing the geographic location of a system allows the determination of the energy source. BRT systems are typically operated with diesel, while LRT systems run on electricity. Petroleum, or crude oil, is the main source of transportation in the US as shown in Table 2.10. Crude oil, is then distilled, refined, and given specific fuel properties to produce Diesel fuel. On the other hand, electricity can come from a large variety of sources as shown in Figure 2.6.



**Figure 2.6 Energy sources**

Tables 2.10 & 2.11 show the distribution of energy consumption by source for transportation in US and Canada, respectively. As it can be seen in Table 2.10, petroleum is the main source of energy for transportation in the US. It accounts for 92.8% of the energy consumed. For Canada 76.1% of the energy consumed comes from motor gasoline.

**Table 2.10 Distribution of energy consumption by source for Transportation in US during 2011**

Source	Percentage
Petroleum	92.8%
Natural Gas	2.7%
Renewable Energy	4.2%
Electricity	0.3%

Source: Davis, 2012

**Table 2.11 Energy use by energy source in Canada during 2009**

Source	Consumption (PJ)
Electricity	2.5 (0.2%)
Natural Gas	1.8
Motor Gasoline	1,070.3 (76.1%)
Diesel Fuel Oil	58.8 (4.2%)
Ethanol	28.4
Propane	5.6

Source: Environment Canada, 2009

## 2.6.2 Energy Consumption

Other than geographic location to obtain information on energy sources, another main factor to determine the pollutants emitted by a mode is its energy consumption. Energy consumption depends on the vehicle type, the fuel source, and the usage. This section gives typical values of the energy consumed in the United States and Canada, considering bus and rail, and different fuel sources.

When energy consumption is being compared, rail is generally assumed to be superior to rubber-tired buses because of low friction. (Puchalsky, 2005) Table 2.12 shows energy consumption in the US for bus and rail for 2010, both in total and per passenger-km for both modes. Energy consumption per passenger kilometer for bus and rail were 2,700 and 1,650 GJ, respectively. Bus consumption of petroleum was 90 thousand barrels per day in the US during 2010, compared to 12.68 million barrels per day in all transportation modes during 2011. The total energy consumption for this year for transportation was 27.1 quadrillion Btu. (Davis et al., 2012)

**Table 2.12 Energy consumption for transportation in US during 2010 (values converted to metric)**

Mode/Source	Consumption (PJ)	GJ / passenger-km
Transit Bus:		2,700
• Gasoline	1.1	
• Diesel	69.5	
• Natural Gas	20.4	
• Electricity	0.7	
Rail Transit:		1,640
• Electricity	49.4	

Source: Davis et al., 2012

Table 2.13 shows the energy use by mode in Canada for 2009. 1,405.8 PJ of energy was used that year for passenger transportation in this country. In this case, passenger car represented the largest energy consumption for the country.

**Table 2.13 Energy use by mode of transportation in Canada during 2009**

Mode	Consumption (PJ)	GJ/passenger-km
Passenger Car	639.9	1,894.4
Urban Transit	32.4	1,634.1
Inter-city buses	5.9	984.1
Passenger Rail	3.1	2,193.9

Source: Natural Resources Canada, 2012

### **2.6.3 Emissions**

Greenhouse gas emissions are difficult to quantify and as a result are often not included by decision makers. Assessing the different emissions of each option is not simple because there are many variables that have to be considered. (Chester et al., 2010; Litman, 2009)

The complexity of quantifying emissions when evaluating different transit modes creates uncertainty as to how this comparison should be made. Puchalsky (2005) in his study presents results in grams per passenger-mile and grams per offered space-mile. He states that comparing emissions in terms of vehicle-miles can create misperception because different types of vehicles are considered. If the output results are to be shown in these terms then appropriate normalizing factors are needed in order to make a fair comparison.

In terms of emissions, electric LRT is considered superior in relation to diesel BRT. Light rail vehicles do not emit propulsion system pollutants when operating, but they are responsible for the fuel cycle emissions from the generation of their electric power. Diesel buses are generally perceived as negative regarding pollution that's directly emitted into their service areas. They are also responsible for the fuel cycle emissions due to refining and other processes. (Puchalsky, 2005)

### **2.6.4 Pollutants and Emissions values**

Emissions from transportation modes contain a large variety of gases and compounds that affect the environment and the public health. Most notably, transportation is a major source of

Greenhouse Gases (GHG) that influences climate change. (US EPA, 2009) Even though there are many pollutants, the main pollutants discussed in this research are Carbon Dioxide, Nitrogen Oxides and Sulfur Dioxide. Carbon Dioxide is the only GHG from these pollutants, but NO<sub>x</sub> and SO<sub>2</sub> emissions are important pollutants that emanate from transportation sources.

Carbon dioxide (CO<sub>2</sub>) is “a colorless, odorless, non-poisonous gas” that is part of the air. This gas emanates mostly from human activities, mainly from fossil fuel combustion. It is considered the main pollutant affecting climate change. US CO<sub>2</sub> emissions from fossil fuels for the transportation sector in 2010 were around 1,750 million metric tonnes as seen in Table 2.14; this accounts for 32.7% of the CO<sub>2</sub> emissions for this country during 2010. Most of US transportation sector’s CO<sub>2</sub> emissions – 97.5% – emanate from petroleum fuels. (Davis et al., 2012)

**Table 2.14 USA Greenhouse gas emissions (million metric tonnes of CO<sub>2</sub> equivalent) for transportation during 2010**

Pollutant	Quantity
Carbon Dioxide	1759.5
Methane	1.6
Nitrous Oxide	19.0
Hydrofluorocarbons, Perfluorocarbons and Sulfur Hexafluoride	58.4
Total	1838.5

Source: Davis et al., 2012

**Table 2.15 Transportation green house gas emissions for 2010 (Million metric tonnes of CO<sub>2</sub> equivalent)**

Mode	CO <sub>2</sub>	Methane	Nitrous Oxide
Medium and Heavy Trucks and buses	405.3	0.1	1.0
Rail	43.5	0.1	0.3

Source: Davis et al., 2012

Nitrogen oxides (NO<sub>x</sub>) are mainly emitted by the combustion of fossil fuels. When concentrations are excessive, NO<sub>x</sub> become an air pollutant. NO<sub>x</sub> create health hazards, ground level ozone, acid rain and smog. They react in the air and form compounds that affect acid deposition. Other environmental issues created by NO<sub>x</sub> are the formation of particulate matter,



the reduction of visibility, the creation of greenhouse gases, which consequently affects global climate change. (Davis et al., 2012; Baukal, 2005; US EPA, 2009)

Sulfur Dioxide (SO<sub>2</sub>) is mainly produced by human sources, especially by industrial activity, as, for example, the generation of electricity from coal, oil or gas. It also originates from the combustion of fossil fuels. Moreover, it is harmful for human health when inhaled. SO<sub>2</sub> is also an important source of acid rain. The SO<sub>2</sub> share in transportation in US is 2.1% of the total emissions, as seen in Table 2.16. (Australian Government, 2005)

As stated before, emissions affect significantly the creation and behavior of greenhouse gases, which are the gases that prevent infrared energy from leaving the atmosphere. These trap the absorbed energy to warm the planet's surface. (Davis et al., 2012) Many pollutants make this effect worse by causing high temperatures in the surface of the earth. The next tables show some emission data regarding USA and Canada greenhouse gas emissions that emanated from transportation during 2010 for USA and 2009 for Canada.

**Table 2.16 Transportation share for US emissions during 2011 (millions of short tons)**

Pollutant	Quantity	Percentage of total
CO	38.56	61.8%
NOx	6.11	50.9%
VOC	3.61	29.8%
PM-2.5	0.21	4.2%
PM-10	0.19	2.7%
SO <sub>2</sub>	0.17	2.1%

Source: Davis et al., 2012

**Table 2.17 GHG emissions in passenger transportation during 2009 in Canada**

Mode	Metric tonnes of CO <sub>2</sub> eq
Total	95.5
Private Cars	43.4 (45.4%)
Buses	3.6 (4%)
Rail	0.2 (0.2%)
Other	48.3 (50.6%)

Source: Natural Resources Canada, 2012

## 2.6.5 Past Emissions Models

Some models have been developed to study the difference in emission generation between different modes of transportation. Emissions studies typically consider only operational elements, basically energy consumption, because emissions related to the specific vehicle are the ones assumed to have the highest impacts. (Chester et al., 2010)

Chester et al. (2010) compared life cycle energy consumption and emissions for urban transportation in metropolitan regions. This is captured for both operation and non-operation components. This paper evaluates three transit-rich metropolitan cities – San Francisco, Chicago and New York City – to determine the environment performance of different modes in these regions. Their model uses travel activity data to generate life cycle emissions inventories to evaluate their external costs. The model also considers trip characteristics, vehicles (active and inactive, manufacturing, and maintenance), infrastructure (construction, operation and maintenance) and fuels (production). It also takes into account vehicle age and speed, vehicle occupancy rates and external costs related to health and GHG.

The results of this research are different for the three regions due to the differences in mode splits, vehicle types, vehicle age, and off-peak and peak characteristics. This paper concludes that in every region automobile emissions constitute almost all CO emissions from passenger travel, and that their life cycle emissions are about 10% larger than other modes. It also finds that diesel commuter rail use and emissions from the electricity generation for metro trains create a high percentage of life cycle emissions of NO<sub>x</sub>. Upstream SO<sub>2</sub> emissions account for more life-cycle impacts than other pollutants because of the electricity generation in vehicle manufacturing and maintenance, construction and operation of infrastructure, and the production of fuel. Considering energy consumption and GHG emissions, for the three regions, automobile worsens from off-peak to peak, while in transit, when increased ridership occurs in peak hours, system performance remains constant or improves. (Chester et al., 2010; Puchalsky, 2005)

Puchalsky (2005) presented in his paper a comparative analysis of the pollution impacts of LRT and BRT. The main objective of this paper is to make a fair comparison between the two modes considering some important emissions. The study compares similar levels of technology, to avoid comparing the most advanced to an obsolete example of the other mode. This study is focused on new semi rapid, medium-capacity transit lines. The pollutants analyzed in this paper are urban or regional emissions of carbon monoxide, volatile organic compounds (VOCs), and NO<sub>x</sub>. The results of this analysis show that LRT systems produce fewer emissions, in the different categories considered, than BRT systems. This remains true when equal technology levels are being compared, and sometimes is also true for some pollutants when superior BRT technologies are compared to standard LRT systems. (Puchalsky, 2005)

These models chose specific regions for comparison, or using a specific set of scenarios. There is no room for new systems to be compared. Emissions compared in both models are similar to the ones compared in the model developed for this thesis, but comparison is made using very different methodologies.

## **2.7 Summary**

This chapter reviewed the literature studied before developing the quantitative model that achieves the objectives discussed in Chapter 1. First, a brief description of the decision making process for a transit mode was given. Then descriptions of the modes studied in this research, LRT and BRT, were presented. Definitions of the modes were given and ongoing debates were discussed and explained. Finally, the main parameters of the model developed were defined and reviewed.

Demand is one of the most important factors for this research. It is usually measured in passengers per hour. The most important value related to the demand is the MLS, which is the section where the maximum passenger volume is found.

The different cost components were discussed in this chapter. Definitions of capital and operating costs were given, and the factors that affect these the most were examined.

Important elements that influence these costs were reviewed, as length of alignment, number of stations, right of way separation, number of vehicles, labor rates, number of operators, and energy and maintenance costs, among others. Typical values were given when available. Cost estimating methods were discussed by reviewing past models that have tried to find a fair comparison between the modes.

The last main factors discussed in this chapter were emissions. The pollutants reviewed included Carbon Dioxide, Nitrogen Oxides and Sulfur Dioxide. These compounds were examined by reviewing their importance and their definitions; and by finding typical values of energy consumption and greenhouse gas emissions. In addition, past models that studied and compared the difference in emissions between different modes of transportation were discussed.

A parametric model is developed for this research after reviewing the literature previously discussed. This model assists in the mode selection process between LRT and BRT, and can be expanded to other modes through future research. Some models exist that produce results that are related to this research but the model developed for this thesis varies greatly from them. The model developed here considers more parameters and inputs to develop a more specific scenario for comparison. Its estimations are not based on specific values that can vary greatly depending on multiple parameters; it is based on user specified data. It considers not only operating data but also system characteristics. Results are presented not only numerically but also graphically for better understanding and analysis. It also allows for testing sensitivity to operating inputs. It provides comparison not only of costs but also of emissions from both modes. It does not make any assumptions about land-use. It lets the analyst use judgment when analyzing the results. Using spatial information when comparing emissions, the model allows the user specify this to obtain data about the fuel source. It is an easy-to-use accessible web-based model.

# Chapter 3

## Methodology

Many cities across North America are considering upgrading their existing transit service or implement new transit technologies that meet their requirements and complement their growth plan. The most commonly evaluated transit technologies include light rail and bus rapid transit. The decision behind technology selection for mid-sized cities often creates debates about which mode would be more appropriate, as discussed in Chapter 2.

Determining the type of transit that will be more cost-efficient and less harmful for the environment, at a specific scenario, requires an extensive evaluation. The complexity behind the cost estimation of rapid transit systems is triggered by the lack of conclusive studies that examine thoroughly all the factors that affect the costs of the system. The same can be said when comparing emissions. The decision making process needs to be meticulous and detailed to increase the likelihood of choosing the best alternative.

The uncertainty decision makers often face when trying to decide which transit mode will meet a city's requirements is the main motivation for this research. As mentioned in Chapter 1, the main objective in this thesis is to develop a parametric cost model that assists decision makers in this process. An easy-to-use interface, accessible via website, was developed. This model considers investment and operating costs and also environmental impacts. It allows the analyst to determine the relative domains of demand for which rail or bus is more cost effective. It also has the capacity to test the sensitivity of specific inputs to the economic factors of the system. The main objective is to determine the conditions under which a particular transit mode is more effective. This model determines the total annual cost and total annual emissions for LRT and BRT, though the methods presented may be easily extended to other modes.

This chapter discusses and reviews the methodology followed to achieve the objectives of this research and the steps followed towards the development of the model. Figure 3.1 shows

conceptually the methodology followed to develop the quantitative model. Each step represents different stages inside the methods: inputs (dashed line), functions (dotted line), break-even point (solid line), parameters (double solid line), outputs (thick line), and the main outcomes (circles).

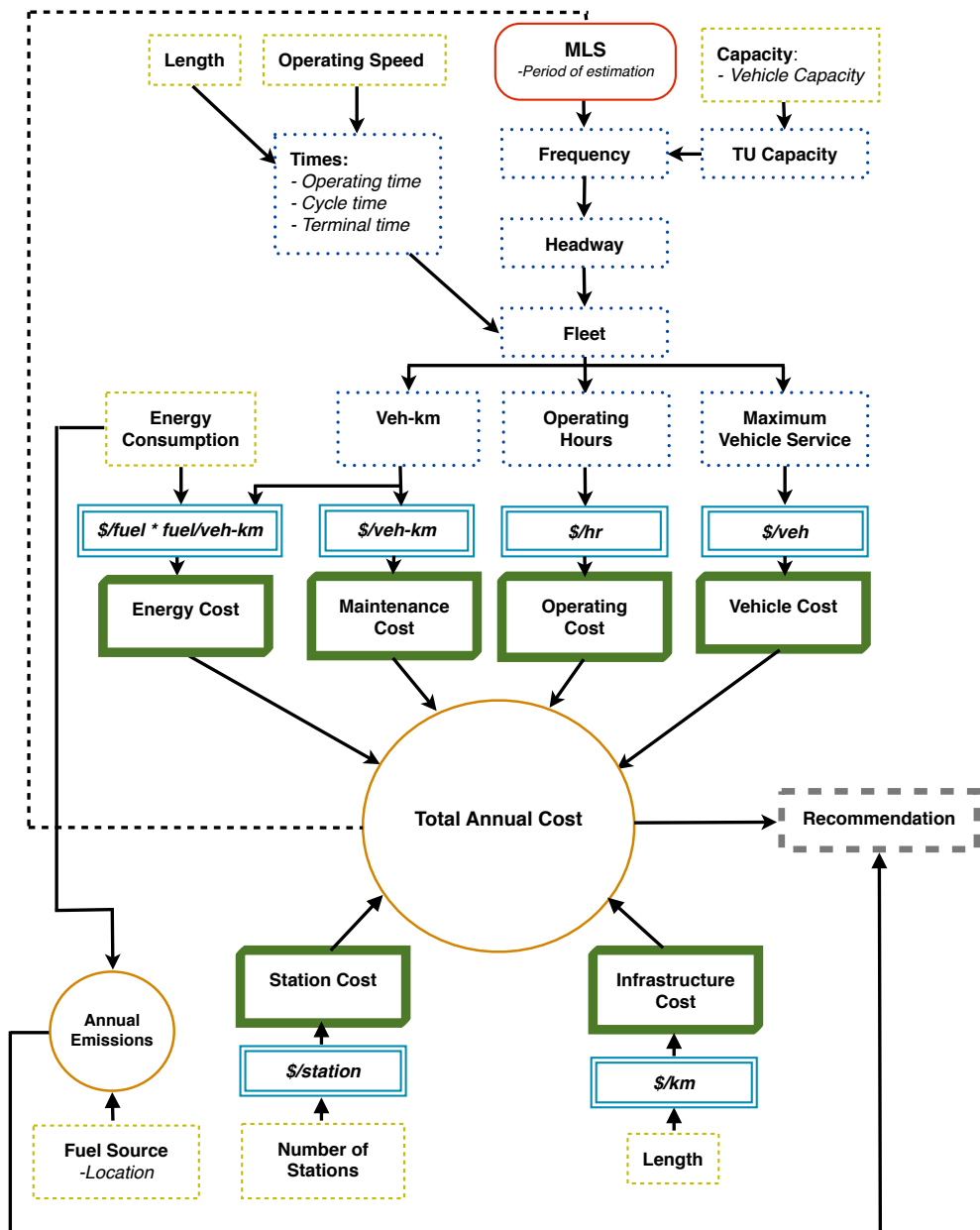


Figure 3.1 Quantitative model methodology

### 3.1 Determining Main Factors

To develop a method of selecting the appropriate transit mode, first, factors that affect this decision are defined. After reviewing the literature three main factors are identified as the most influential in the decision making process: Demand, Cost and Emissions. These are shown in Figure 3.2, which also identifies the main components that affect their behavior.

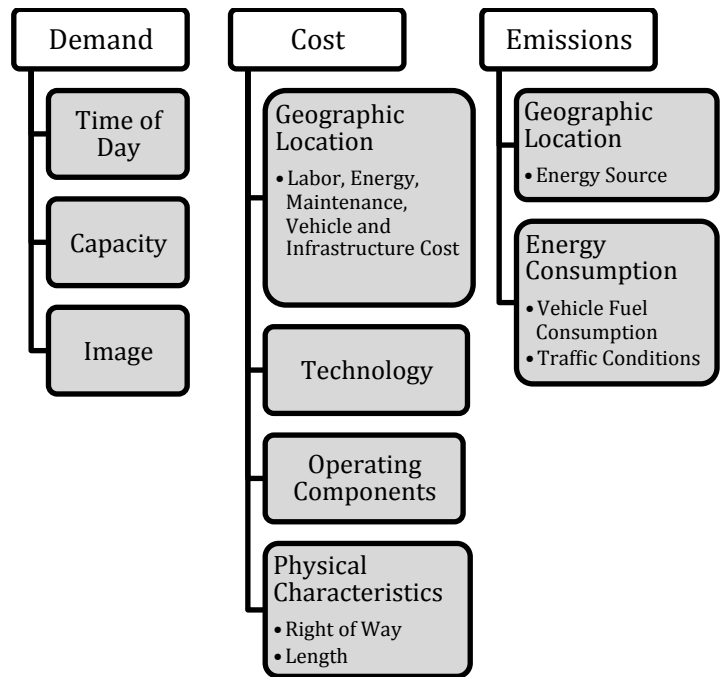


Figure 3.2 Main components

Prior to developing a model, the main factors that influence this decision making process should be evaluated. These three factors, demand, costs and emissions, will be discussed in this section in order to understand their importance in this research and how they affect the analysis that the model developed achieves.

### 3.1.1 Demand

Demand, defined previously in Chapter 2, is the volume of passengers that use the system during a specific period. The most important factor of demand in this research is the Maximum Load Section. The Maximum Load Section (MLS) is the section of the line on which the maximum passenger volume is found. This is shown in Figure 3.3. The figure shows the passenger volume that is transported through the line, and how the MLS is determined. In this figure the MLS can be found in section D-E. This value is a very important factor in the planning process because it defines the capacity needed, which then affects the number of vehicles in use, the number of operators needed, the frequency at which the system will run, among other factors that affect the main costs analyzed in this model.

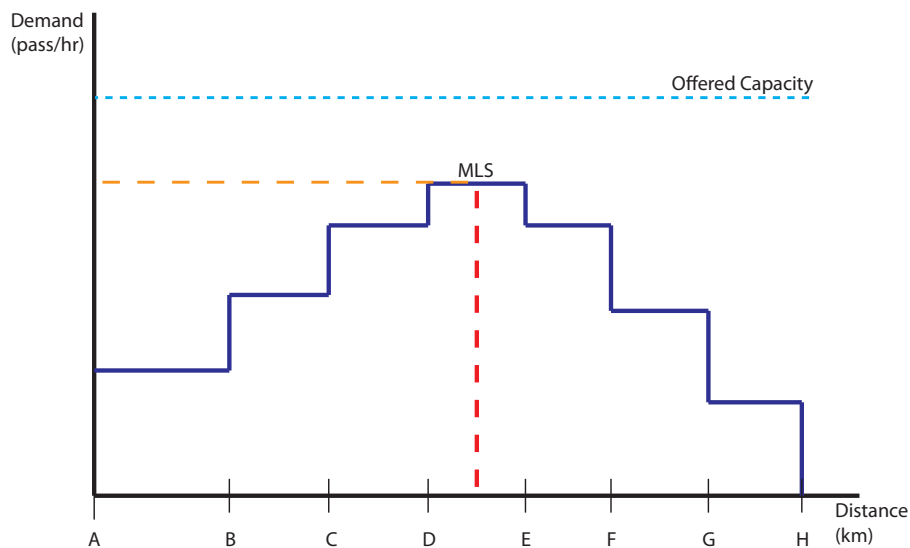


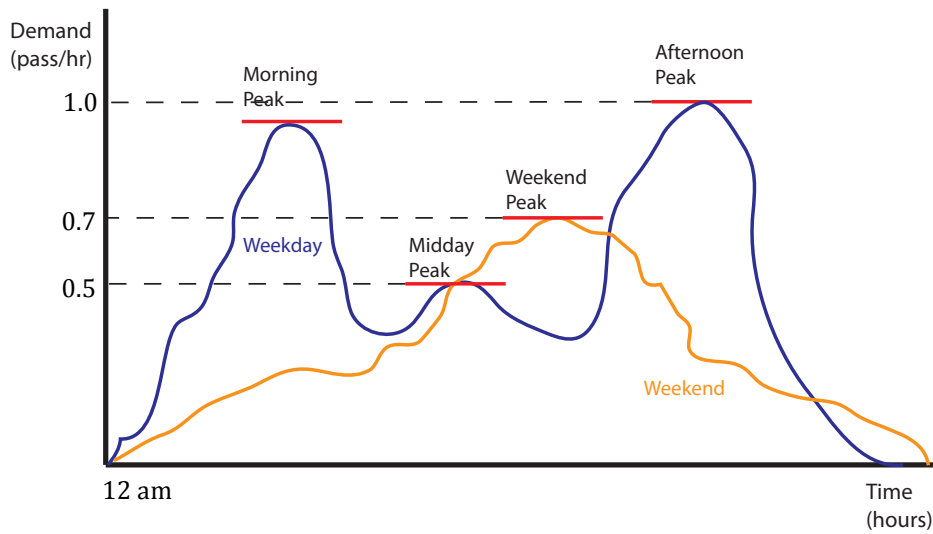
Figure 3.3 Maximum Load Section (MLS)

#### 3.1.1.1 Demand Levels

Variations of demand occur often during one day; to be able to apply these variations to the model developed, demand levels were defined. In each period of the day, demand is defined as a function of the peak period, as shown in Figure 3.4 (the values used in this figure are an example of how they are measured in this analysis). Each of the demand levels represents a



percentage of the peak demand; this value is represented by  $\beta$  when the model functions are defined later in this chapter. For example, as shown in Figure 3.4, the weekday afternoon peak constitutes the maximum demand. The weekend peak is only 70% of the weekday peak. In the model these periods and their demands are defined.



**Figure 3.4 Demand levels**

Demand levels don't affect the number of vehicles in the fleet, but they do affect the number of vehicles in operation and, therefore, the number of operators, at any time of the day. As a result, they affect the total operating hours in a day, and the total annual operating hours, directly affecting then total labor costs. These levels are also an important factor of total annual energy consumption, and the total vehicle-kilometers traveled. Affecting also energy costs and maintenance costs.

### 3.1.2 Cost

When evaluating alternative transit technologies, cost is typically the main factor considered. As discussed in Chapter 2, cost is the principal factor analyzed by decision makers when comparing different transit modes.

Costs relating to transportation systems can be divided into two main groups: capital costs and operating costs. Capital costs include vehicle, infrastructure and station costs, while operating costs include labor, maintenance and energy cost. Labor costs include wages or salaries and maintenance cost include vehicle and infrastructure maintenance.

The main cost that is found in this model is the Total Annual Cost for each mode. There are 6 main components to these costs: Labor, Vehicle, Maintenance, Infrastructure, Station, and Energy. These main costs are defined in Chapter 2. Cost inputs and outputs are examined and defined in the next sections. The steps followed to obtain the annual cost are also discussed in this chapter.

### **3.1.3 Emissions**

Emissions are substances that are discharged into the air. One of the main sources of pollutants emitted to the environment is transportation. As environmental awareness increases, emissions become a very important factor in the selection of a transit mode. Emissions should be considered when determining which mode would affect less negatively the environment. Transportation emissions include greenhouse gases, which in high concentrations warm the surface of the planet, and as a result, aggravate climate change. A high concentration of pollutants can also be harmful to health. (U.S. EPA, 2009)

The interest of including emissions as an output for comparison in the model emerges when realizing that decision makers, due to their difficulty to quantify, often disregard them. The approach to include emissions in this research is to measure a quantity of emissions rather than a cost. Cost depends greatly on the amount of tax, if existent, that is applied to the quantity of emissions. Quantity (tonnes) depends on the energy source, which depends on the system's geographic location, and it seemed as a more achievable database dependent of just two factors, geographic location and energy consumption. Also the decision is based in previous literature where quantities seemed as a more useful result.

The emissions considered for this research are: CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub>. Emissions depend greatly and mainly on energy consumption. Chapter 2 discussed thoroughly the different pollutants, their definitions, and energy consumption and emission rates. Emissions are an output of this model. The model determines the quantity of pollutants that each mode will emit during a year of usage, discussed further in this chapter.

## **3.2 Model Development**

The first step taken in the development of the model was to determine what data were needed in order to find the desired outcome. The main focus of the model was to let the analyst create the scenario on which both modes would be compared. This lets the user model a future or existing system to compare two, or more, transit modes. This section discusses the data required and the parameters needed to find the desired values.

### **3.2.1 Data Requirements**

The model developed in this thesis requires a series of inputs to be entered by the analyst in order to run. The inputs used in this model shape the base scenario on which the two modes, LRT and BRT, are compared. Table 3.1 lists the inputs used in the model with the variables or symbols used, their units and definitions.

**Table 3.1 Model inputs**

Inputs	Variable	Units	Definition
Passenger Demand for Maximum Load Section	MLS	Pass/hr	Maximum passenger volume in the maximum load section along the line.
Vehicle Capacity	$c_v$	sps/veh	Spaces for passengers offered by a vehicle
Capacity Utilization Coefficient	$\alpha$	pass/space	Load Factor, passengers per space, a measure of comfort
Operating Speed	$v_o$	km/hr	Average speed of a transit unit along the line. Speed offered to the public
Line Length	L	km	One-way distance from one terminal to the other along the alignment
Terminal Time	$t_t$	min	Time a transit unit spends at a line terminal
Number of Stations	$NSta$		Facility for passenger boarding, alighting, waiting and transfer.
Hours of Operation		hrs	Scheduled hours in a day. These are divided by demand levels
MLS Ratio per Level	$\beta$	% of max MLS	Weight of MLS per demand level. How MLS varies with time period of analysis.
Vehicle Spare Ratio		%	Percentage of spare vehicles available
Coupling			Determines if there's more than one vehicle per transit unit

Source of definitions: Vuchic, 2005; Sullivan et al., 2003

### 3.2.1.1 North American Average Values

For the previously discussed inputs, mean North American values are provided as default values. These values were obtained from multiple sources, researching different systems across North America, previously discussed in Chapter 2, and also from reports made for both modes. These values are helpful when the user does not have all the data required to run the model. These are listed in the following tables.

**Table 3.2 North American average values**

Input	LRT	BRT
Operational Speed	20 – 70 km/hr <sup>1, 2, 3, 8</sup>	20 – 50 km/hr <sup>4, 5</sup>
Vehicle Capacity	180 – 245 sps/veh <sup>3, 6, 8, 14</sup>	120 sps/veh <sup>7</sup>
Labor Cost	\$20 – 30/hr <sup>8, 9</sup>	
Energy Consumption	3.5 – 3.7 kWh/km <sup>3</sup>	0.91 – 1.72 L/km <sup>10</sup>
Energy Cost	\$ 0.075 – 0.16 / kWh <sup>11, 12</sup>	\$ 0.72 – 1.08 / L <sup>13</sup>
Vehicle Capital Cost	\$ 3 M – 6 M / veh <sup>14</sup>	\$ 0.5 M – 1 M / veh <sup>14, 15, 17</sup>
Service Life	20 – 40 years <sup>16</sup>	8 – 15 years <sup>15</sup>
Vehicle Maintenance	\$ 0.4 – 0.6 / km <sup>20</sup>	\$ 0.1 – 0.5 / km <sup>10</sup>
Station Construction Cost	\$ 0.5 – 9 M <sup>17, 18, 19</sup>	
Infrastructure Construction Cost	\$ 25 – 113.5 M/km <sup>14</sup>	\$ 6.5 – 105 M/km <sup>14, 15, 17, 19</sup>

<sup>1</sup>Sources listed on footnote (Currency Converted to US\$2011)

**Table 3.3 Example of Light Rail Vehicle costs in different cities**

City	Cost per Vehicle (USD)
Portland, Oregon	\$3.6 M
Charlotte, North Carolina	\$3.3 M

Source: Casello et al., 2009

**Table 3.4 Different cost of BRT vehicles**

Model	Cost (US\$)
40-ft. low-floor	\$340,000 - \$380,000
45-ft. low-floor	\$550,000 - \$720,000
60-ft. low-floor	\$480,000 - \$950,000 (or more)

Source: Henke, 2009

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<sup>1</sup> SEWRPC, 1998; <sup>2</sup>Hammonds, 2002; <sup>3</sup>City of Calgary, 2011; <sup>4</sup>APTA, 2010; <sup>5</sup>CUTA, 2007; <sup>6</sup>Siemens, 2007; <sup>7</sup>Zimmerman et al., 2004, <sup>8</sup>Vuchic, 2005; <sup>9</sup>CUTA, 2011; <sup>10</sup>Hemily et al., 2003; <sup>11</sup>EIA, 2012; <sup>12</sup>Manitoba Hydro, 2012; <sup>13</sup>World Bank, 2010; <sup>14</sup>Casello et al., 2009; <sup>15</sup>Levinson et al., 2003; <sup>16</sup>Transportation Action Ontario, 2012; <sup>17</sup>Danaher, 2009; <sup>18</sup>Hsu, 2005; <sup>19</sup>Kittleson and Associates, 2007; <sup>20</sup>Pilgrim, 2000

**Table 3.5 Examples of infrastructure construction costs for LRT**

City	Infrastructure Cost/Mile (million USD)
Charlotte (1)	\$44
Calgary (2)	\$24.5
Edmonton (2)	\$41.7
Dallas (2)	\$45.5

(1) Light Rail Now, 2012 (USD 2000)

(2) Calgary Transit, 2002 (USD 2000)

**Table 3.6 Examples of infrastructure construction cost for BRT**

City	Infrastructure Cost/Mile (million USD)
Pittsburgh's West Busway	\$44
Ottawa's Transitway	\$13
Pittsburgh's East Busway	\$17
Cleveland	\$4
Hartford	\$6

*Values rounded*

Source: Kittleson and Associates, 2007

### **3.2.2 Parameters**

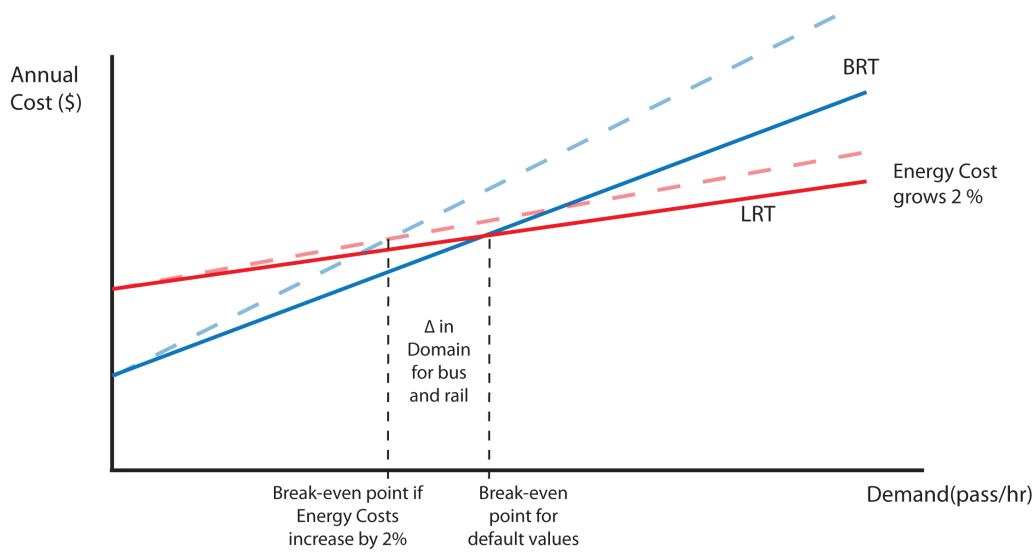
Parameters are included in the model as inputs as well, but do not affect the operating components and characteristics of the system. These parameters affect the costs and emissions obtained after calculating the operating factors. These are listed in Table 3.7

**Table 3.7 Parameters**

Inputs	Variable	Units	Comments
Labor Rate	<i>LR</i>	\$/hr	Varies as a function of location, labor rules
Energy Consumption Rate	<i>ECR</i>	kWh/km or L/km	LRT – Electricity BRT – Diesel
Energy Rate	<i>ER</i>	\$/kWh or \$/L	Depends on location, markets
Vehicle Maintenance Rate	<i>VMR</i>	\$/veh-km	Cost of vehicle maintenance. Varies as a function of distance traveled.
Infrastructure Maintenance Rate	<i>IMR</i>	\$/km	Cost of alignment maintenance.
Growth Rates	$g_k$	%	Growth Rates per Cost. Reflects expected changes in parameters over time. Applied to labor, energy and maintenance costs.
Vehicle Capital Cost	<i>VCC</i>	\$/veh	
Service Life	<i>SL</i>	Years	Time period over which the model will analyze the alternatives to be compared
Period of Study	<i>P</i>	Years	
Interest Rates	<i>i</i>	%	Discounting rate in the analysis
Station Construction Cost	<i>SCC</i>	\$/Sta	
Infrastructure Construction Cost	<i>ICC</i>	\$/km	

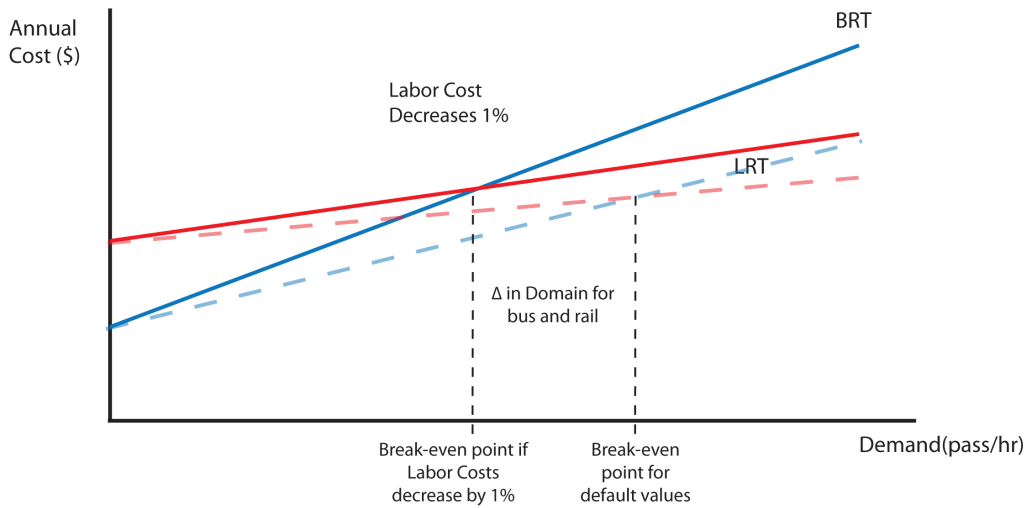
The uncertainty behind these parameters lies mostly in the geographic location of the system. For example, labor costs will not be the same in North America as in a developing country. These parameters affect specific outputs the most. Most of these parameters are linked to specific outputs, and this is why their effect is more noticeable when comparing different ranges. Figures 3.5 & 3.6 show how the behavior of these parameters can affect the output of this model. These figures show how variations in a parameter can alter the break-even point.

Figure 3.5 shows an example of how an increase in the energy cost can reduce the BRT domain for this specific scenario. This causes the break-even point to be a smaller demand than with the default values, in this example.



**Figure 3.5 Example of effect of energy cost on break-even point**

Another example of the parameters effect in the output is represented in Figure 3.6. This example shows conceptually how a decrease in the labor cost can cause the break-even point to move towards higher demands, and give BRT a larger demand than with the original values.



**Figure 3.6 Example of effect of labor cost on break-even point**



## 3.3 Model Structure

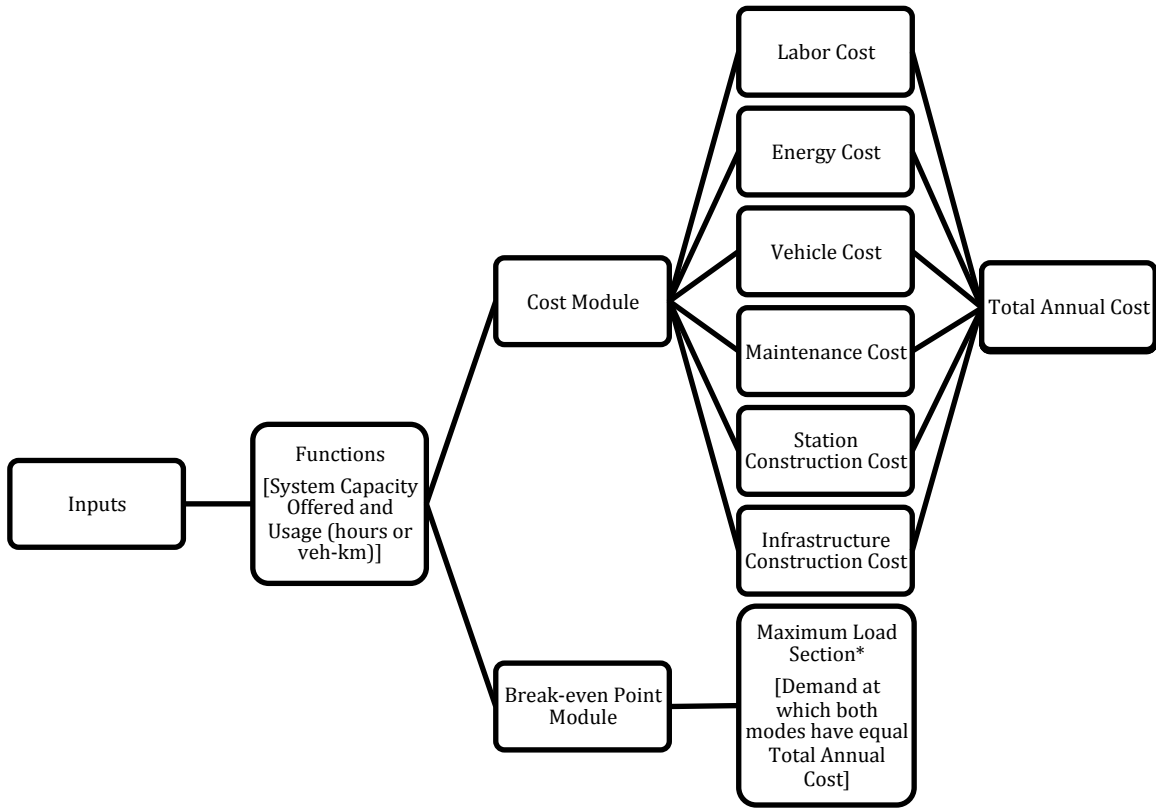
The main goal of this research is the development of a web-based, accessible model that:

- Finds annual costs for the transit modes being evaluated,
- Finds the most appropriate transit mode for a specific scenario,
- Finds the demand at which both transit modes have the same annual costs,
- Tests the sensitivity that outputs have to inputs,
- Finds annual emissions produced for both modes, and
- Shows results that are visual and easy to understand.

To achieve these objectives, the model was formulated based on the “Concept of Equivalence”. Equivalence implies that all alternatives are compared in every detail possible when they serve the same purpose. Obviously, the challenge is how to ensure equivalence. (Sullivan et al., 2003) For example, the alternatives compared in this model have different useful lives, and this should be taken into careful consideration. This section reviews the model structure and the main processes inside the model.

### 3.3.1 Model Development

The initial platform for this model was developed using Excel. Figure 3.7 shows the general structure of the model. This diagram displays the general process that occurs and the main outputs. It also shows the first modules developed inside the model, which are an annual cost calculation for each mode. Then the break-even point is calculated with the use of the goal seek function, which finds the demand at which both systems have the same annual costs. The main difference between these two modules is that the cost module uses a constant demand as entered by the user, while the break-even point module uses a variable demand to determine the point where both modes have equal annual costs. These modules are explained in detail in the next sections.



**Figure 3.7 General structure of the model**

### 3.3.1.1 Cost Module

The cost module of the model finds the main costs affecting the total annual cost of the system. Figure 3.8 shows the structure of the cost module including the inputs used for each process, the values found inside each process and the main outputs of the cost model.

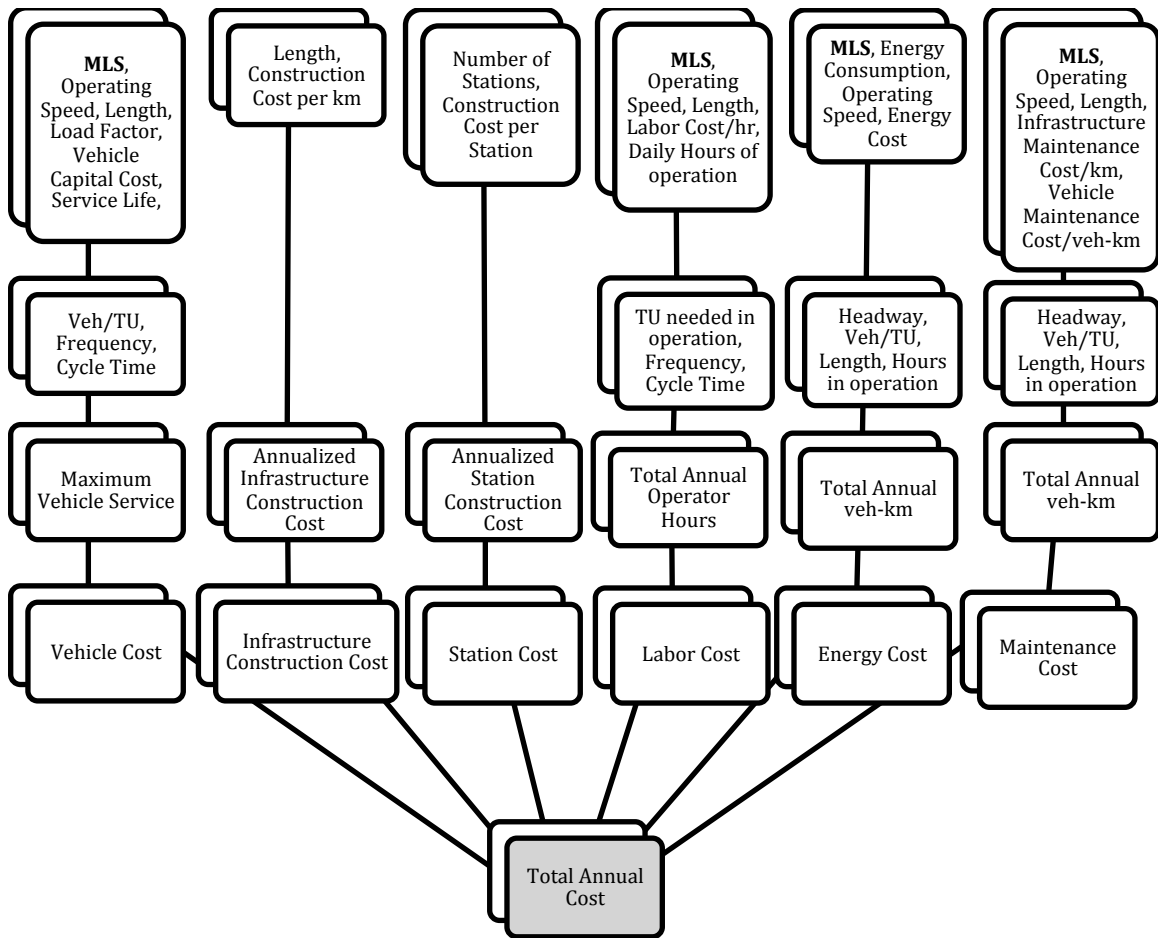


Figure 3.8 Structure of the cost module

### 3.3.1.2 Break-Even point Module

The break-even point module is the second part of the model. This module finds the relative demand at which both modes have the same annual cost. The procedure is the same as in the Cost Module, using the same inputs and functions, but it doesn't use the MLS value entered as an input. This process is done by using the goal seek function in Excel. With this, the model obtains the MLS at which total annual costs between modes is equal (within the limits of the goal seek function).

### 3.3.1.3 Sensitivity Analysis

Another important feature of the model developed is the ability to test the sensitivity to the inputs. The model allows the user test how much a change in a set of specific inputs will influence the total operating costs. With the use of slider bars, the analyst is able to visualize the sensitivity of the inputs in the output value. The model also develops a radar graph that shows the percent change on these total operating costs. The graph provides the image of each system and helps the analyst visualize what percentage the output changes because of the change caused to the input.

Sensitivity analysis is very important and helpful when trying to determine how the outputs can be affected by specific inputs. Sensitivity is a relative magnitude on how an estimated value changes when a measure or input is also changed. (Sullivan et al., 2003) Figures 3.9, 3.10 & 3.11 show how this was developed and displayed.

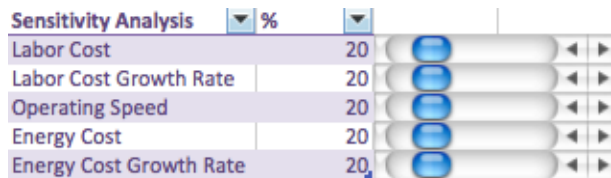


Figure 3.9 Input percent change

Sensitivity Analysis	% Change	
	LRT	BRT
Labor Cost	3%	3%
Labor Cost Growth Rate	7%	3%
Operating Speed	-6%	-8%
Energy Cost	1%	6%
Energy Cost Growth Rate	0%	2%

Figure 3.10 Numerical output in sensitivity analysis

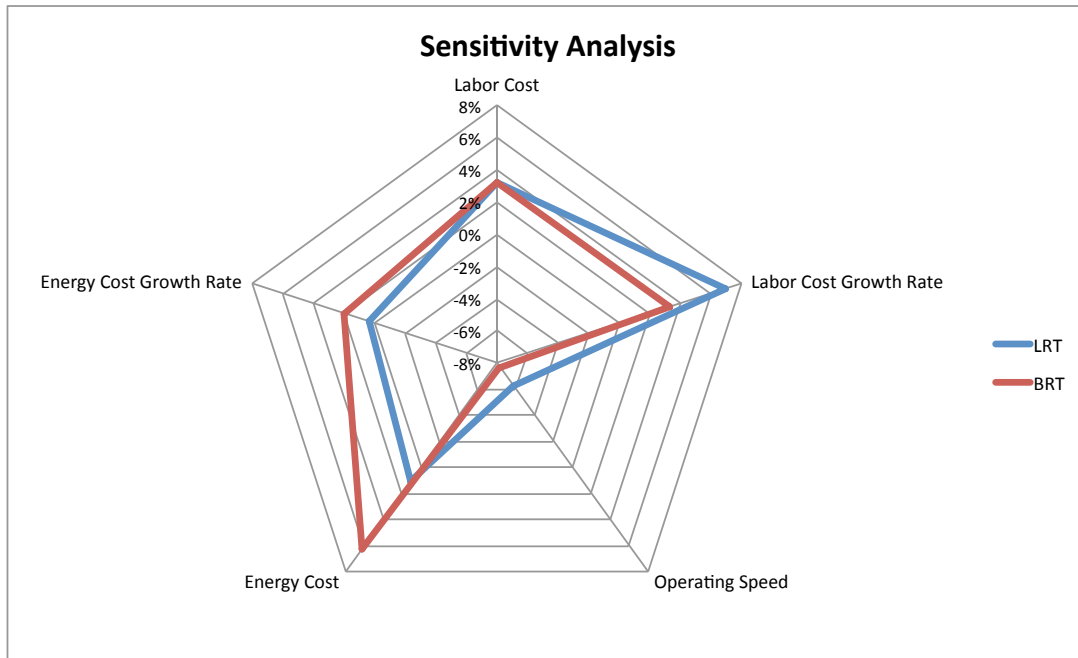


Figure 3.11 Radar graph in sensitivity analysis

### 3.3.2 Migration to Web-based

After developing the model using Excel another objective emerged: accessibility. The main motivation behind wanting to create an accessible model was to be able to test the model's functionality under a wide range of inputs from multiple locations. Even though Excel is a very useful tool to develop a model like this, it is not the most feasible way to make it accessible worldwide. This is why the development of the model, from this point on, was migrated to a web-based platform. This shift was made using mainly JavaScript and HTML. It was made possible by integrating these two languages together to create a dynamic user-based website.

JavaScript is a small and lightweight programming language used to create dynamic and interactive websites. (Chapman, 2012) JavaScript, in this model, works with a series of functions, similar to commands that perform the processes needed in order to find the values for other functions or outputs. These processes use the inputs previously discussed and equations that will be defined in the next sections.

The second language used was HTML. HTML stands for HyperText Mark-up Language. It consists of a series of characters and symbols inserted to indicate how a file (that consists on words and images) will be displayed on a World Wide Web page. It requires a browser to display the file. (Rouse, 2005)

The model is coded in JavaScript, as mentioned before, and allows users to create their own scenarios by entering the values and characteristics their system will have. These inputs are then used inside the model, with the equations that will be discussed in the next sections, to find the values needed before obtaining the main outputs.

Figure 3.12 shows a screenshot of how the inputs are displayed on the website. All inputs are defined using a hover function. Clarity of the inputs needed is necessary, so a definition is shown so that the analyst knows what types of values are required. When the cursor hovers the input name a description appears for the user to better understand what the expected input is. The values shown in this figure are the default values, which are taken from North American averages, discussed in previous sections. From these inputs, the model computes the total annual costs, the passenger demand at which the two technologies have equal life cycle costs over the analysis period, and the annual energy consumption for both modes.

# Santiago and Casello Model

[Click here to download Sensitivity Analysis](#)

## Input Values

\*Please enter the values below in its corresponding space. Numerical values only.

	<u>LRT</u>	<u>BRT</u>
<u>Passenger Demand for Maximum Load Section (pass/hr):</u>	<input type="text" value="1500"/>	<input type="text" value="1500"/>
<u>Operational Speed (Vo = km/hr):</u>	<input type="text" value="45"/>	<input type="text" value="25"/>
<u>Length (km):</u>	<input type="text" value="15"/>	<input type="text" value="15"/>
<u>Number of Stations:</u>	<input type="text" value="10"/>	<input type="text" value="10"/>
<u>Total Hours of Operation:</u>	<input type="text" value="18"/>	<input type="text" value="18"/>
Hours per Demand Period:		
<u>Demand Level 1 (Peak):</u>	<input type="text" value="6"/>	<input type="text" value="6"/>
<u>Demand Level 2 (Off-Peak):</u>	<input type="text" value="9"/>	<input type="text" value="9"/>
<u>MLS Ratio for Level 2:</u>	<input type="text" value="0.8"/>	<input type="text" value="0.8"/>
<u>Demand Level 3 (Late Evening):</u>	<input type="text" value="3"/>	<input type="text" value="3"/>
<u>MLS Ratio for Level 3:</u>	<input type="text" value="0.6"/>	<input type="text" value="0.6"/>
<u>Demand Level 4 (Weekend Day):</u>	<input type="text" value="9"/>	<input type="text" value="9"/>
<u>MLS Ratio for Level 4:</u>	<input type="text" value="0.8"/>	<input type="text" value="0.8"/>
<u>Demand Level 5 (Weekend Evening):</u>	<input type="text" value="4"/>	<input type="text" value="4"/>
<u>MLS Ratio for Level 5:</u>	<input type="text" value="0.6"/>	<input type="text" value="0.6"/>
<u>Vehicle Capacity:</u>	<input type="text" value="220"/>	<input type="text" value="120"/>
<u>Capacity Utilization Coefficient:</u>	<input type="text" value="0.8"/>	<input type="text" value="0.8"/>
<u>Terminal Time:</u>	<input type="text" value="5"/>	<input type="text" value="5"/>
<u>Vehicle Spare Ratio:</u>	<input type="text" value="10"/>	<input type="text" value="10"/>
<u>Labor Cost (\$/hr):</u>	<input type="text" value="25"/>	<input type="text" value="20"/>
<u>Operating Cost Growth Rate(%):</u>	<input type="text" value="2"/> %	<input type="text" value="2"/> %
<u>Energy Consumption (kWh/km) or (L/km):</u>	<input type="text" value="3.6"/>	<input type="text" value="1.32"/>
<u>Energy Cost:</u>		
<u>Electricity Cost (\$/kWh):</u>	<input type="text" value="0.12"/>	
<u>Diesel Cost (\$/L):</u>		<input type="text" value="0.90"/>
<u>Energy Growth Rate(%):</u>	<input type="text" value="2"/> %	<input type="text" value="2"/> %
<u>Vehicle Capital Cost (\$):</u>	<input type="text" value="4500000"/>	<input type="text" value="750000"/>
<u>Service Life (Years):</u>	<input type="text" value="30"/>	<input type="text" value="12"/>
<u>Period:</u>	<input type="text" value="40"/>	<input type="text" value="40"/>
<u>Interest Rate (%):</u>	<input type="text" value="5"/> %	<input type="text" value="5"/> %
<u>Maintenance Cost:</u>		
<u>Vehicle Maintenance: (\$/veh-km)</u>	<input type="text" value="0.5"/>	<input type="text" value="0.3"/>
<u>Infrastructure Maintenance: (\$/km)</u>	<input type="text" value="120000"/>	<input type="text" value="100000"/>
<u>Maintenance Growth Rate (%):</u>	<input type="text" value="2"/> %	<input type="text" value="2"/> %
<u>Station Construction Cost (\$/Station):</u>	<input type="text" value="500000"/>	<input type="text" value="500000"/>
<u>Infrastructure Construction Cost (\$/km):</u>	<input type="text" value="69000000"/>	<input type="text" value="56000000"/>
<u>LRT Coupling?:</u> <input type="checkbox"/>		

Figure 3.12 Inputs as shown in the web-based model

Another main function used in the web-based model is the ability to check for errors. When unreasonable values or typos are entered in the input boxes, the model shows a message highlighting the error and specifying where it is located.

### 3.3.2.1 Web-based Break-Even point

The break-even point module is programmed to calculate costs for a range of MLS values to formulate a graph. This graph is the result of the relationship between costs and demand. As demand increases, costs increase as well, but their slope is different because both systems increase at different rates. This causes the lines formed to cross, and the point where this happens determines the break-even point. The concept of how the break-even point is determined within the model was discussed in the previous chapter. Figure 3.13 presents how the graph is shown in the model. The lumpiness of this graph inside the model is due to constant costs for ranges of MLS, when MLS creates a change in costs the change is very noticeable and it creates the unevenness of the lines.

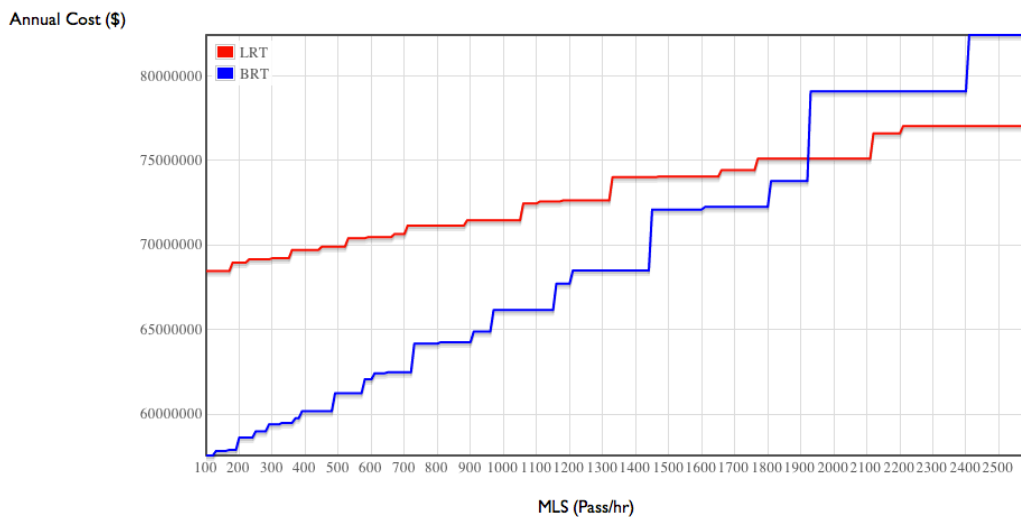
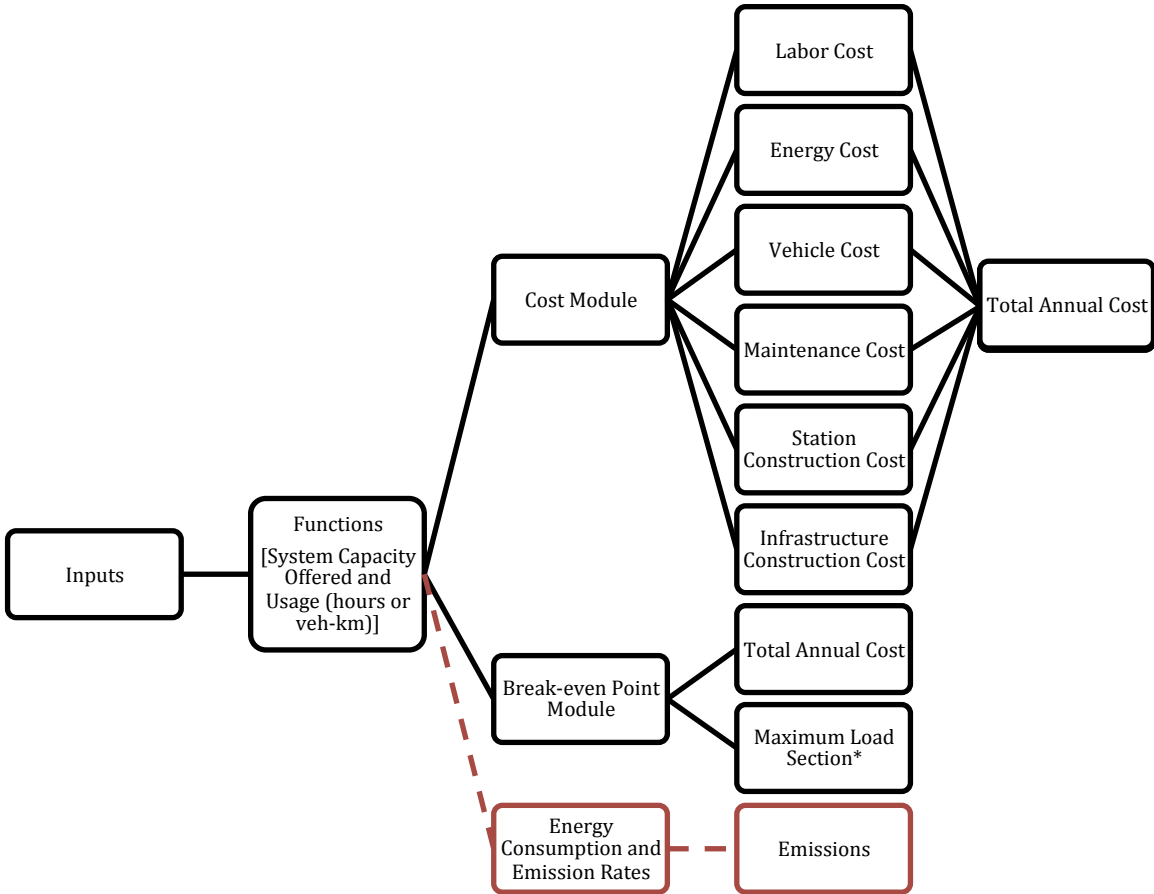


Figure 3.13 Break-even point as shown in the web-based model



### 3.3.3 Emissions Module

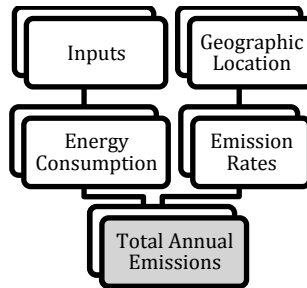
The emissions module was added to the web-based model.



**Figure 3.14 General structure of the model post addition of emissions module**

The emissions module determines the quantity of emissions in one year for both systems for three specific pollutants (CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub>). A general structure of this module is presented in Figure 3.15. As can be seen in this diagram, this module's main factors are energy consumption and emission rates. Energy consumption is determined by the user, and the emission rates are completely dependent on the location of study. This is because emission rates depend on the energy source, which is different for every geographic location. The user selects the country of study (USA or Canada are the ones currently available, though it has the ability to be extended

to more) and then the region. With this, it determines the emission rate for this particular region and calculates the total annual emissions for each pollutant for each system.



**Figure 3.15 Structure of emissions module**

How the outputs are shown in every of these modules is discussed further in this chapter.

## **3.4 Model Functions**

The model developed in this research works with the inputs discussed previously to achieve the main objectives of this research. Many intermediate values, calculated throughout the model, are factors that should be mentioned and defined before explaining how they act within the model. These intermediate values are calculated inside JavaScript functions, as mentioned before. Each function can work individually or with each other, but they are all needed to find the values required. These are coded in the website and act as commands using the equations listed next. The most common operating factors that are used in this model are explained briefly next, these include: headway, frequency, capacity, travel time and speed. Table 3.8 summarizes and defines the main equations used in the model.

**Table 3.8 Equations in the model (Model inputs shown in bold)**

Value	Equation Number	Equation	Definition	Comments
Maximum Load Section per Demand Level	3.1	$MLS_i = \beta \cdot MLS$	Value of MLS in demand level $i$	$\beta =$ MLS Ratio See Figure 3.4
Vehicle Capacity	3.2	$c = c_v \cdot \alpha$	Number of spaces for passengers per vehicle	
Vehicles per TU	3.3	$n = 1$ <i>if</i> $\frac{MLS}{c} < 12,$ <i>else it is 2</i>	Vehicles per Transit Unit	This is applicable only if coupling is selected for LRT.
TU Capacity	3.4	$C = c \cdot n$	Number of spaces for passengers per transit unit	
Frequency	3.5	$f = \frac{MLS}{C}$	Number of transit units per hour passing the same point in the line	$f: TU/hr$
Headway	3.6	$h = \frac{60}{f}$	Time interval between subsequent vehicles	$h: min/TU$
Operating Time	3.7	$T_o = \frac{120L}{v_o}$	Scheduled time interval between departure from the first terminal and arrival to the other terminal	It is the time from departure of the first terminal until departure from the same terminal for the next trip.  $min$
Cycle Time	3.8	$T = T_o + 2t_t$	Time it takes a TU to do a round-trip on the line	$min$
Transit Units	3.9	$N = \left[ \frac{T}{h} \right]^+$	Transit units needed for operating the transit line to meet demand	$TU$
Present Value	3.10	$P = A \frac{1 - (1 + g)^n (1 + i)^{-n}}{i - g}$	Present value for annual cost calculated	$g =$ growth rate $i =$ interest rate $n =$ period of study

			considering growth rate	\$
Annual Cost	3.11	$A = P \frac{i(1+i)^n}{(1+i)^n - 1}$	Annualized value for present cost calculated with equation 3.11	\$
Annual Cost	3.12	$A = P \frac{i}{1 - \frac{1}{(1+i)^n}}$	Used for capital costs as vehicle costs and infrastructure	\$
Equivalent Annual Cost	3.13	$EAC = A * \frac{PS}{N}$	Used for capital costs as vehicle costs and infrastructure	$PS$ is period of study $N$ is service life \$

Source for equations and definitions: Vuchic, 2005; Sullivan et al, 2003

Functions are coded in order to find the values mentioned earlier. The model first finds all the operating values as capacity, headway, frequency and cycle time, and then with all of these values it finds the annual usage, in hours or vehicle-kilometers. These values are found for different demand levels, which are designated by the user. The weight of the MLS in each demand level is specified by the user as a ratio. Both of these are then used in all of the calculations for the different demand levels to adjust the capacity offered during different times a day.

These operating components are then used to find annual values of usage as total annual operator hours and total annual vehicle-kilometers. The model then computes the different cost components mentioned before, which are: Operating Costs (Labor, Maintenance and Energy) and Capital Costs (Vehicle, Infrastructure Construction and Station Construction).

Operating costs are based on annual usage of the system, hence are annual values when calculated, but a growth rate is applied to these values. Capital costs, on the other hand, are a one-time investment that needs to be converted into an annual cost for this analysis. This is done with the use of an interest rate and a period of study. Capital costs also have service lives different than the period of study; hence an equivalent annual cost needs to be found.

When all these costs are finally in an annual basis, then the total costs are found. The Total Annual Cost is calculated by adding all the annualized costs. This, and all of the previous calculations are made for both, LRT and BRT.

## **3.5 Outputs**

After determining the process to achieve this research's objectives, the outputs were found. The main outputs of the model developed for this research, as mentioned before, include total annual costs, emissions and the relative demand at which both modes have equal life-cycle costs. The model, as previously discussed, is divided into three main modules, which separate the different outputs. These outputs are going to be discussed in this section.

### **3.5.1 Cost Module**

The cost module determines the total annual cost for both systems. These costs are formed by the six main costs mentioned before: labor, energy, maintenance, vehicle, infrastructure construction and station construction costs. These main outputs are then shown in the website numerically and graphically for better visualization, and are found for both BRT and LRT. Table 3.9 lists, displays the equations used and defines these outputs. The equations shown below are simplified using only user-supplied variables. Full derivation of these equations is shown Appendix A.

**Table 3.9 Cost module outputs**

Outputs	Equation Number	Variable	Equation	Definition
Labor Cost	3.14	$LC$	$LC = LR * \sum_i hours_i$ $* \left[ \left( \frac{60L}{v_o} + t_t \right) \frac{\beta \cdot MLS_i}{30 \cdot c_v \cdot \alpha \cdot n} \right]^+$ <p style="text-align: center;"><i>Growth rate is applied with Eq. 3.10 and 3.11</i></p>	Includes labor costs as operator wages
Energy Cost	3.15	$EC$	$EC = ER * ECR$ $* \sum_i \frac{\beta \cdot MLS_i}{c_v \cdot \alpha} \cdot 2 \cdot L \cdot hours_i$ <p style="text-align: center;"><i>* days</i></p> <p style="text-align: center;"><i>Growth rate is applied with Eq. 3.10 and 3.11</i></p>	Costs of energy used by system
Vehicle Cost	3.16	$VC$	$VC = VCC * \left[ \left[ \left( \frac{60L}{v_o} + t_t \right) \frac{\beta \cdot MLS_{max}}{30 \cdot c_v \cdot \alpha} \right]^+ \right]$ $* \frac{P}{SL}$ <p style="text-align: center;"><i>Value is annualized using Eq. 3.12</i></p>	Capital costs of the vehicles needed
Maintenance Cost	3.17	$MC$	$MC = VMR * \left[ \sum_i \frac{\beta \cdot MLS_i}{c_v \cdot \alpha} \cdot 2 \cdot L \cdot hours_i \right]$ <p style="text-align: center;"><i>* days + (IMR * L)</i></p> <p style="text-align: center;"><i>Growth rate is applied with Eq. 3.10 and 3.11</i></p>	Maintenance of infrastructure and vehicles
Total Station Construction Cost	3.18	$TSCC$	$TSCC = NSta * SCC$ <p style="text-align: center;"><i>Value is annualized using Eq. 3.12</i></p>	Cost of construction per station
Total Infrastructure Construction Cost	3.19	$TICC$	$TICC = L * ICC$ <p style="text-align: center;"><i>Value is annualized using Eq. 3.12</i></p>	Cost of infrastructure construction per length (usually cost per kilometer or mile)
Total Annual Cost	3.20	$TAC$	$TAC = LC + EC + MC + Annualized(VC + TSCC + TICC)$	Sum of all the previous costs

Figure 3.16 shows a screenshot of how the numerical outputs for this module are shown in the website model. These are the results achieved when using the default values.

**Output**

Labor Cost:	\$ 1,421,421.0	\$ 3,419,517.0
Energy Cost:	\$ 840,630.15	\$ 4,352,556.6
Vehicle Cost:	\$ 3,512,777.4	\$ 7,897,778.7
Maintenance Cost:	\$ 3,372,930.7	\$ 3,099,113.1
Station Construction Cost:	\$ 291,390.81	\$ 291,390.81
Infrastructure Construction Cost:	\$ 60,317,896.	\$ 48,953,655.
<b>Total Annual Cost:</b>	<b>\$ 69,757,046.</b>	<b>\$ 68,014,011.</b>
	LRT Total Annual Cost	BRT Total Annual Cost

**Figure 3.16 Numerical outputs for the cost module**

The graph that visually presents these outputs is made in a radar graph to show the magnitude of these individual costs in respect to one another. This makes it easier to compare both modes in each of these individual outputs, and also compare all costs in relation to each other. Selecting a radar graph as the media of display was influenced by the visual element it provides. Figure 3.17 shows an example of this graph as is presented in the website (this figure displays the results shown above).

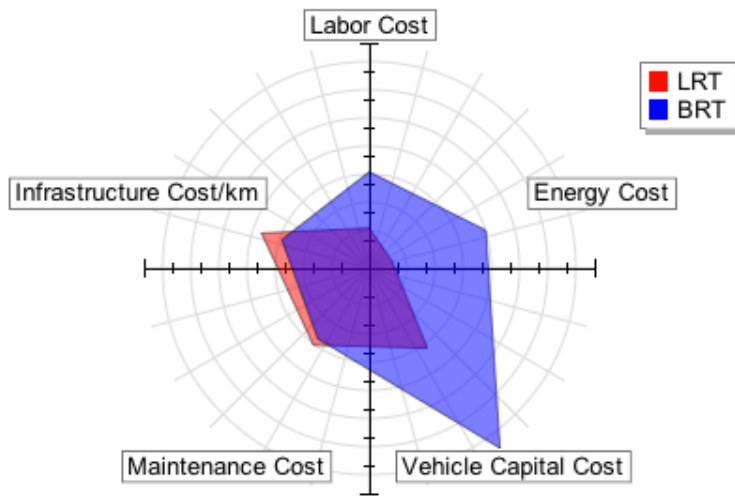


Figure 3.17 Graphical output for the cost module

Another graph represented in this module shows the frequency of each system for different demand levels during a weekday. This shows the vehicles per hour needed for each mode at these demand levels, and makes it easier to visually compare the difference. This graph is shown in Figure 3.18.

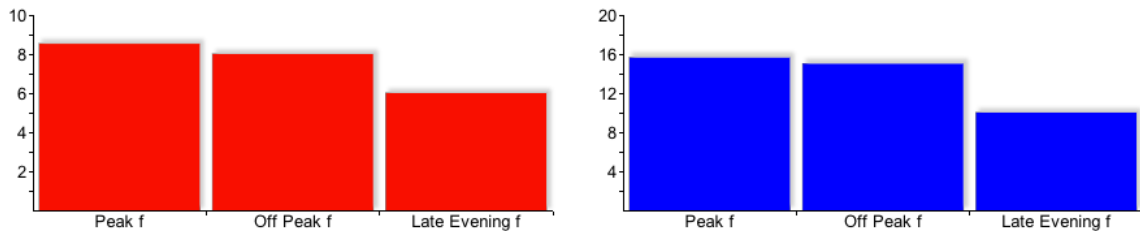


Figure 3.18 Vehicle frequency output

### 3.5.2 Break-even point Module

Another main output, which has been discussed, is the demand at which both modes have the same annual cost. This output is shown graphically, as shown in Figure 3.19. It uses specifications of the system and finds then the ranges of demand versus cost and shows where



the two modes meet. In this point both systems have the same annual cost and same passenger demand. The concept behind this analysis was discussed previously in this chapter.

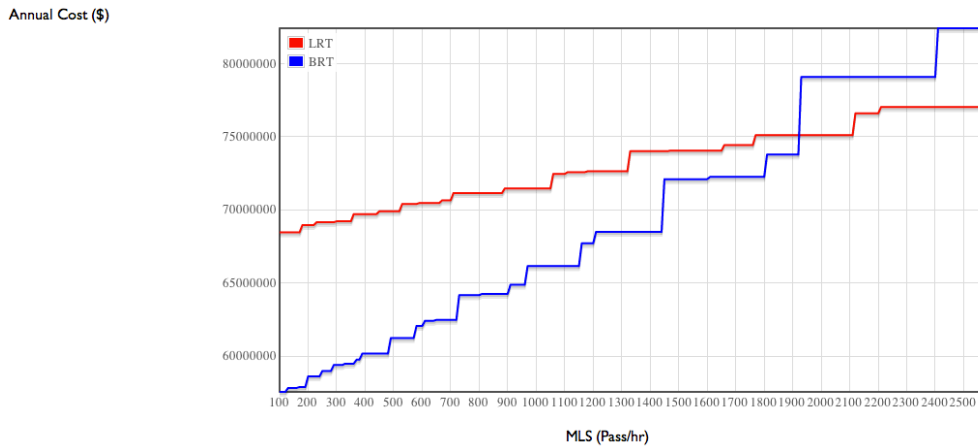


Figure 3.19 Break-even point module output

### 3.5.3 Emissions Module

The emissions module works with the energy consumption calculated within the model. The model calculates annual energy consumption for both modes and afterwards, when energy source is determined, it calculates the annual emissions for three pollutants: CO<sub>2</sub>, NO<sub>x</sub>, and SO<sub>2</sub>; which were discussed and defined in Chapter 2.

The energy source, as previously explained, is determined by the system’s geographic location. This location is an input in the model. The two countries chosen for this module were USA and Canada. After a country is selected a map is displayed, to list multiple regions of study.

After country and region are chosen, the model uses the functions designated to obtain the emission rates for each of the pollutants mentioned above. The emission rates used in this module were obtained from two main sources: NERC (North American Electric Reliability Corporation) and GHGenius (from the Office of Energy Efficiency of Natural Resources Canada). These are then used to obtain the total emissions, taking into account the annual energy

consumption for each mode. Figure 3.20 shows an example of how the output is presented in the website.

LRT Emissions:  
NO<sub>x</sub> (t)=     
SO<sub>2</sub> (t)=    
CO<sub>2</sub> (t)=    
BRT Emissions:  
NO<sub>x</sub> (t)=    
SO<sub>2</sub> (t)=    
CO<sub>2</sub> (t)=

**Figure 3.20 Emissions module output**

This chapter has reviewed and discussed the research methodology and tools used to meet the objectives.

# Chapter 4

## Case Studies

### 4.1 Application of the Model

The model developed in this thesis is applicable mainly to mid-sized cities, which are interested in implementing new, or improving existing transit systems. In many mid-sized cities, the most commonly considered transit systems are BRT and LRT. The model as developed emphasized in these two technologies, but the methods could be easily extended to apply it to other technologies as well. The model was applied to four cases to determine which mode would be more appropriate in these scenarios. This chapter will discuss a brief description of these four cases.

The selection of these specific case studies is due to the availability of the data and whether or not the city or region is going or have been through this decision making process. Both the Region of Waterloo and the City of Victoria were chosen because they were recently going through the decision making process of implementing one of these two transit technologies; Cleveland's BRT was chosen for being a recently implemented successful BRT system in North America; and Mexico City's system was chosen to understand the concept of the model from a developing country point of view, and see how the sensitivity to the inputs and parameters in these cases affect the outcome even more. Even though Mexico City is not a mid-sized city it presents a unique case because of its low labor and energy costs, and the sensitivity to these, rather than in the other cases studied.

### 4.2 Case Studies

The cases that will be studied include: the Region of Waterloo in Ontario; Victoria, British Columbia; Cleveland, Ohio; and Mexico City. The model used the data pertaining to these

regions for future systems currently under study and/or development – Waterloo and Victoria – as well as existing systems – Cleveland and Mexico City – to compare costs and emissions of BRT and LRT. The goal of the model is to determine which system would or would’ve been more appropriate in these different locations under the location-specific parameters.

### 4.2.1 Region of Waterloo, Ontario

Located in Southern Ontario, around 100 kilometers west of Toronto, is the Region of Waterloo. This Region consists of three cities: Cambridge, Kitchener and Waterloo. Population in this region is more than 553,000, and it is one of the fastest-growing areas in Ontario. It is expected to reach a population of 729,000 by 2031. The high number of activities in the region is mainly due to two universities, the University of Waterloo and Wilfrid Laurier University, and a community college, Conestoga College Institute of Technology and Advanced Learning, combined these post-secondary schools have around 50,000 students. (Region of Waterloo, 2010)

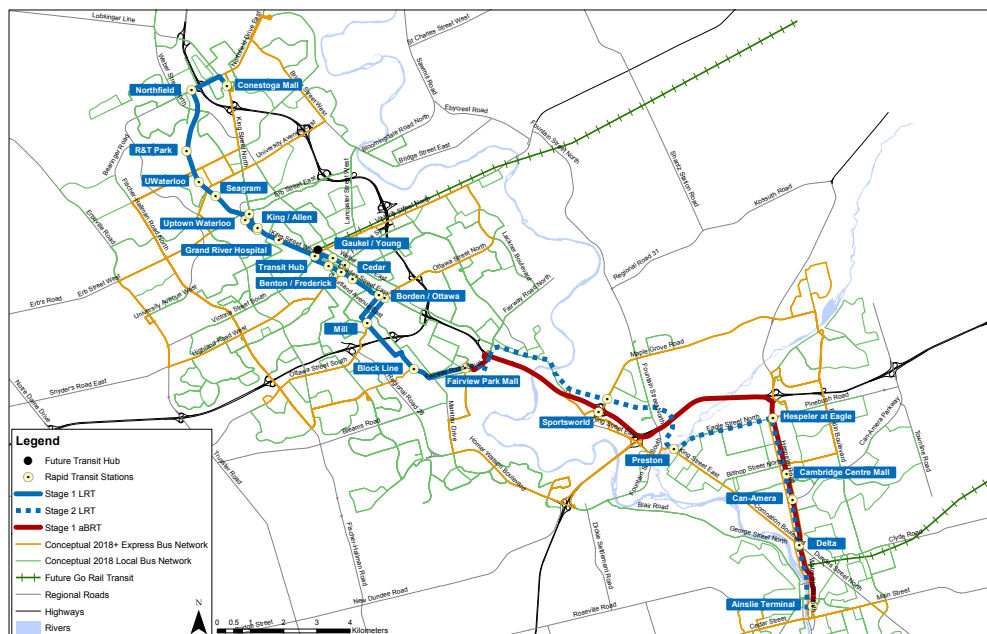


Figure 4.1 Proposed LRT alignment for Waterloo Region (Source: Region of Waterloo)

The alternative of rapid transit was studied and developed to be applied in the Region. Figure 4.1 shows the proposed rapid transit alignment for the region. The main objectives to implement rapid transit are: to alleviate urban sprawl and create attractive and livable urban spaces in the central transit corridor; to provide travel alternatives for people; and to reduce the need for road construction. The Region believes that this plan will provide the best “long-term environmentally sustainable solution” to accommodate Waterloo Region’s future growth and transportation needs. The main goal of this plan is to encourage development in areas that are already developed – by intensification – to protect farmland, and also to attract more riders. (Region of Waterloo, 2012)

In 2006 the Environmental Assessment of Rapid Transit began to identify the best rapid transit alternative for the Region. In these early stages of the proposal the main uncertainty was which technology of rapid transit, BRT or LRT, would be more appropriate for the Region. The most common concerns about the rapid transit implementation were the ridership and population growth projections, the costs and affordability, the increase of taxes, amongst others. (Region of Waterloo, 2012)

Newspaper articles about the decision making process emphasized on the ongoing debates at that time. BRT advocates argued that buses would be less expensive and still be a good choice, while rail supporters said that buses would not attract sufficient development or riders. Many negative responses about the LRT were received at the time, specifically because of its high costs. Debates were reported even within councilors and planners. Accusations on unbiased preference of trains over buses were made. Main concerns were always about the amount of money about to be invested. (Outhit, 2010a; Outhit, 2010b; Outhit, 2011a)

According to surveys made during the decision making process there was a generational split in the rapid transit preference. Older people preferred rapid buses, while younger ones stated that decisions to move into the city were influenced mainly by the proposed light-rail system. (Pender, 2011) Main arguments for supporters of both rapid transit systems were that even though trains are more expensive, they do offer more capacity and attract development, they are also more attractive to passengers. On the other hand, buses are cheaper, hence providing

more cost-effectiveness, and they're also more flexible. Key differences were noticed mostly around costs, benefits, operations and redevelopment. (Outhit, 2011b)

Finally, LRT was chosen. The project was finally approved in May 2012. This system will connect the three cities of the Region. Stage one of the implementation consists of a 19 km long LRT and a 17 km long aBRT (adapted Bus Rapid Transit) system. It will have 22 stations along the 36 km corridor. The estimated capital cost is \$818 million. This capital cost includes design and construction costs, property acquisition, utilities relocation, construction of storage and maintenance facilities, and park and ride lots. (Region of Waterloo, 2012)

## 4.2.2 Victoria, British Columbia

Victoria is located in the southern tip of Vancouver Island in British Columbia. It has a population of 83,000 and it is the capital city of the province. The transit system currently active in Victoria consists of local bus service provided by BC Transit. (City of Victoria, 2012)

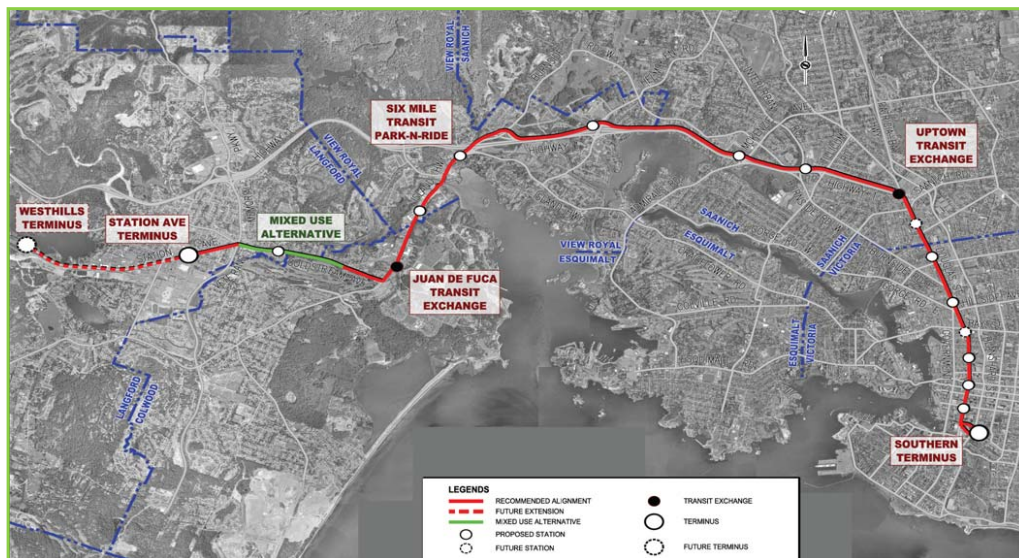


Figure 4.2 Proposed LRT alignment for Victoria (Source: BC Transit)

BC Transit is currently planning and developing a new rapid transit system for Victoria; proposed system alignment is shown in Figure 4.2. This system is intended to connect

Victoria's city center to the West Shore. Studies were made to determine which rapid transit system would be able to meet the requirements of the region. On April 2011, after many studies, discussions and reports, LRT was recommended as the preferred technology. (BC Transit, 2012)

Total capital and operating expenses for this system are estimated to be \$1.2 billion. The other options that were considered would also be expensive. BRT estimates were \$520 million and maintaining the current system was estimated to be \$250 million. BRT would be the less expensive option but only in the short term, when a higher capacity is anticipated after 15 years an upgrade to LRT would be required. (Victoria News, 2011)

### **4.2.3 Cleveland, Ohio**

Cleveland, Ohio, once the fifth largest city in America, is now the thirty-second. Population in Cleveland was of 396,815 in 2010. Since the 1980s Cleveland population growth rate has been decreasing; in 1990 the city's population was 505,672. This began and got worse while urban sprawl continued. (City of Cleveland Planning Commission, 2002(a)(b); US Census, 2010)

Trying to change this, and revitalize their downtown core, Cleveland implemented a BRT system. The Euclid corridor was expected to completely redo Euclid Avenue. Concerns of its cost-effectiveness were also there during the decision making process. (WKYC, 2003) This system has been successful and has even increased transit ridership since its opening date in 2008, and it has won international recognition. It has helped redefine and rebuild the financial core of the city. (RTA Healthline, 2012)

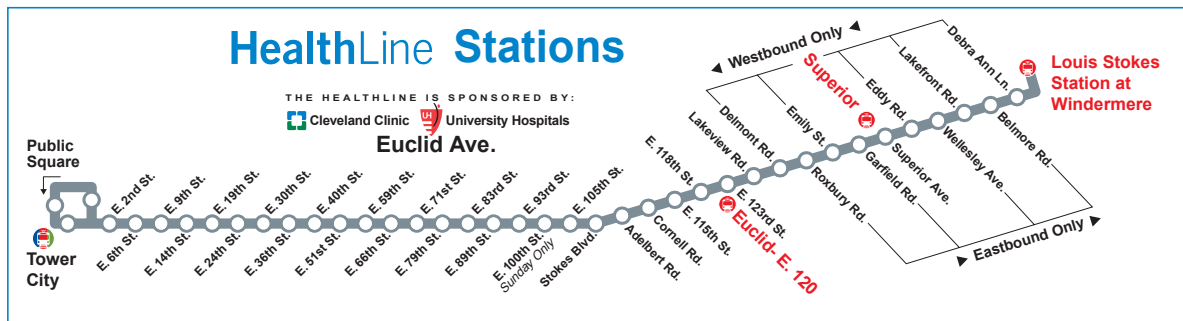


Figure 4.3 BRT alignment for Cleveland's Healthline

The Healthline runs through 10.9 km of Euclid Avenue, the heart of downtown Cleveland, at a completely separated RoW, connecting the city's cultural and educational institutions. It runs 24 hours a day 7 days a week, with 58 stops along the way. This system is helping the Euclid Corridor to return as a financial activity center for economic growth. (RTA Healthline, 2012)

#### 4.2.4 Mexico City, Mexico

Mexico City is the capital city of Mexico. It is one of the most important political, financial, educational and cultural centers of North America. It is among the world's richest cities, it produces more than a third of the gross national income of Mexico. Population in 2011 marked 8,857,188 with a population density of 6,000 people/km<sup>2</sup>. (Mexico City, 2012)

BRT was chosen as one of the choices for improved transit for Mexico City because of recent success with BRTs on developing cities as Bogota's Transmilenio and Curitiba's system. Estimates involving capital costs of the construction of this BRT were only four percent of the costs involved in the construction of the metro rail extension. This is one of the reasons the implementation of the BRT became an option, rather than expanding the existing metro rail. (Parry et al., 2009)

In 2009, Mexico City opened to the public the first line of their BRT system, Metrobús. The system alignment is shown in Figure 4.4. It was implemented as a central part of development in the Region trying to provide a good alternative to people who only have public transit as an



option. Metrobús is a system based on high tech and large capacity buses. These operate in exclusive lanes, and stations are elevated with integration to other systems. (Mexico City, 2012)

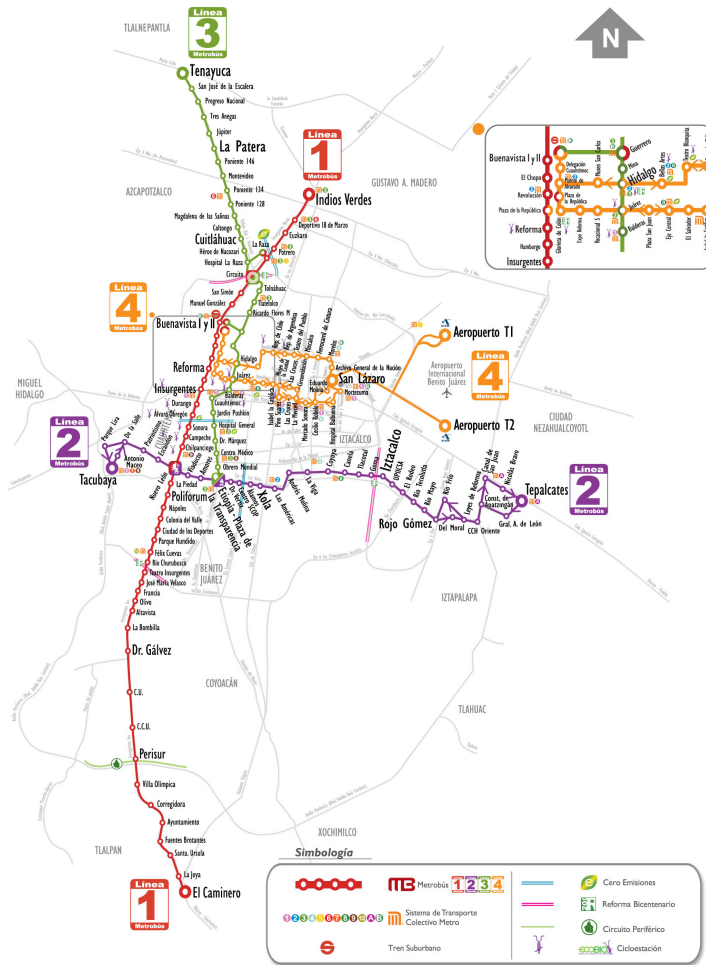


Figure 4.4 Metrobus alignment in Mexico City (Source: Mexico City)

## 4.3 Data and Parameters

Most of the data used to develop these case studies was obtained directly from the transit agencies developing these systems. The data unavailable from the transit agencies was either found through research and other literature. North American values, discussed and listed in Chapter 3, were applied when needed.

The case studies were applied by using the data given, and also by changing some of the values test their sensitivity. The values used for each system will be listed and discussed in Tables 4.1 and 4.2.

**Table 4.1 Input data for case studies**

Inputs	Region of Waterloo	Victoria, BC	Cleveland, OH	Mexico City
Passenger Demand for Maximum Load Section (pass/hr)	1665	1500	1500 <sup>2</sup>	12,000
Operational Speed (Vo = km/hr)	30	LRT: 50	56	18
Length (km)	36	16	11	30
Number of Stations	23	14	58	46
Total Hours of Operation	18.5	20	24	16
Hours per Demand Period				
Demand Level 1 (Peak)	6 <sup>2</sup>	5	8	2
Demand Level 2 (Off-Peak)	9 <sup>2</sup>	11	10	9 <sup>1</sup>
Demand Level 3 (Late Evening)	3.5 <sup>2</sup>	4	6	5 <sup>1</sup>
Demand Level 4 (Weekend Day)	10 <sup>1</sup>	10 <sup>1</sup>	18.5	16 <sup>1</sup>
Demand Level 5 (Weekend Evening)	8.5 <sup>1</sup>	10 <sup>1</sup>	5.5	N/A
MLS Ratio for Level 2	0.8 <sup>1</sup>	LRT: 0.8 BRT: 0.5	0.5 or 0.33	0.5
MLS Ratio for Level 3	0.6 <sup>1</sup>	LRT: 0.53 BRT: 0.33	0.17	0.17
MLS Ratio for Level 4	0.6 <sup>1</sup>	0.8 <sup>1</sup>	0.33	0.56
MLS Ratio for Level 5	0.4 <sup>1</sup>	0.53 <sup>1</sup>	0.17	N/A
Vehicle Capacity	222	LRT: 180 – 240 BRT: 120	100	160 - 240
Capacity Utilization Coefficient	80% <sup>2</sup>	80% <sup>2</sup>	80% <sup>2</sup>	90%
Terminal Time	5 min <sup>2</sup>	5 min <sup>2</sup>	5 min <sup>2</sup>	2 min
Vehicle Spare Ratio	14.3%	10% <sup>2</sup>	5%	0%
LRT Coupling? (Yes/No)	No	Not Specified	N/A	N/A
Population Density (people/km <sup>2</sup> )	2,800	Metro: 495 City: 4,109.4	1,971.9	6,000

<sup>1</sup> Values assumed from values obtained from agencies

<sup>2</sup> Values taken from North American averages

Figure 4.5 shows the demand level ratios in respect to the peak level.

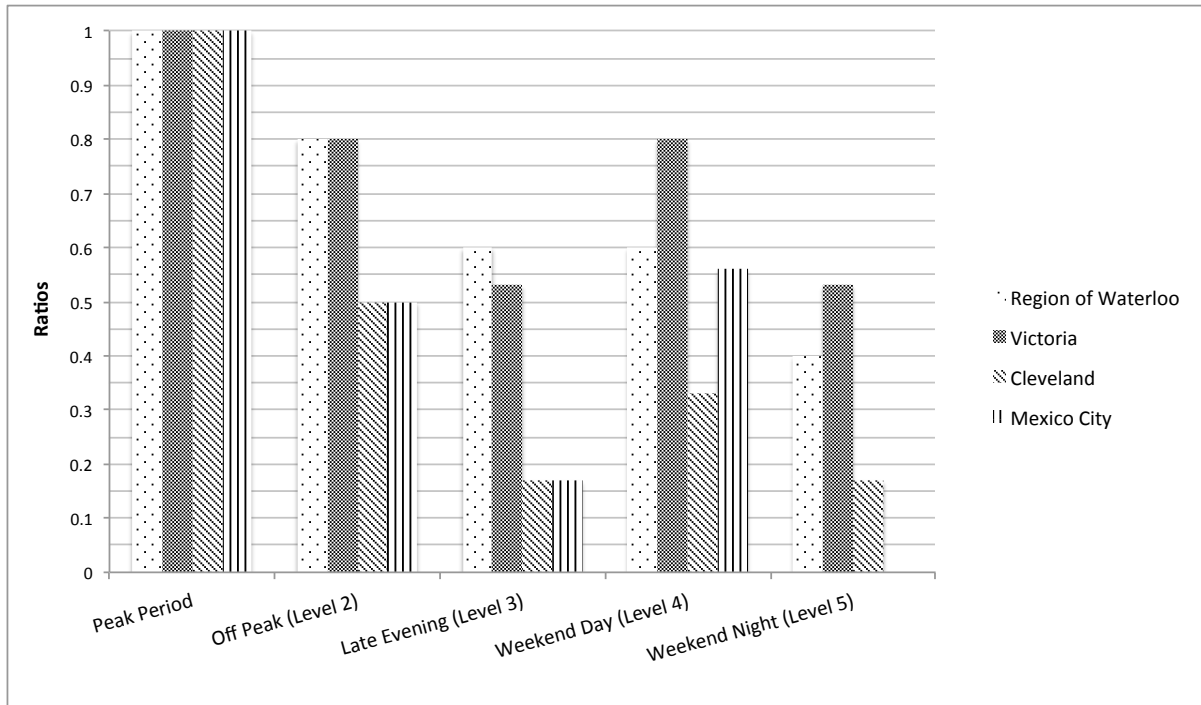


Figure 4.5 Demand ratios compared to peak period

The objective behind these ratios is to include in the model the hourly variations of demand. These determine the capacity that should be offered at different times of the day.

**Table 4.2 Input parameters for case studies**

Parameters	Region of Waterloo	Victoria, BC	Cleveland, OH	Mexico City
Labor Cost (\$/hr)	26.24	26	15 – 24	8 – 10 <sup>1</sup>
Operating Cost Growth Rate (%)	2.5	2.0	2.0	2.0
Energy Consumption (kWh/km) or (L/km)	3.6 kWh/km <sup>1</sup>	3.6 kWh/km <sup>1</sup>	1.0 L/km <sup>1</sup>	0.7 L/km
Energy Cost				
Electricity Cost (\$/kWh)	0.088	0.068	0.13 <sup>1</sup>	0.143
Diesel Cost (\$/L)	1.25 <sup>1</sup>	1.31 <sup>1</sup>	0.79 (1.06 <sup>1</sup> )	0.87
Energy Growth Rate (%)	2.5	2.0	2.0	2.0
Vehicle Capital Cost (\$/veh)	4M	LRT: 6 M BRT: 2 M	0.76 - 1 M	0.2 - 0.4 M
Service Life (Years)	30	LRT: 30 <sup>1</sup> BRT: 12 <sup>1</sup>	12	12 <sup>1</sup>
Period of Study	40	40	40	40
Interest Rate (%)	5%	10%	5%	5%
Maintenance Cost				
Vehicle Maintenance (\$/veh-km)	0.5 <sup>2</sup>	0.5 <sup>2</sup>	0.35 <sup>1</sup>	0.3 <sup>2</sup>
Infrastructure Maintenance (\$/km)	120,000	120,000 <sup>2</sup>	100,000 <sup>2</sup>	50,000 <sup>1</sup>
Maintenance Growth Rate (%)	2.5	2.0	2.0	2.0
Station Construction Cost (\$/Station)	\$562,500	Included in infrastructure construction cost	0.5 M <sup>1</sup>	0.1 M <sup>1</sup>
Infrastructure Construction Cost (\$/km)	15M	LRT: 28.6 M BRT: 14.8 M	25 M	2 M

<sup>1</sup> Values obtained from research

<sup>2</sup> Values taken from North American averages

This chapter presented the case studies that were applied and analyzed for this research. Four cases were introduced and the values used for each were listed and reviewed. The results from these studies will be discussed and analyzed in the next chapter.

# Chapter 5

## Results and Discussion

The development and application of a parametric cost model that assists in the technology selection process, considering investment costs, operating costs and environmental impacts is the main goal of this thesis. An easy-to-use and accessible model was developed for this research to help decision makers choose a system that will meet a city's requirements. It allows planners and engineers to determine the relative domains of demand for which rail and bus are more cost effective, giving a detailed cost estimation, showing the different cost factors, helping show the sensitivity of the inputs to each of these costs.

The application of the model will be discussed in this chapter, showing the results and analysis of the case studies introduced in Chapter 4.

### 5.1 Cost Module Results

As discussed in Chapter 3, the model is divided into three main modules; this section will show and discuss the results obtained in the cost module.

The cost module calculates the life cycle costs for both transit modes, for each of the cost categories previously discussed (Labor, Energy, Maintenance, Vehicle, Station and Infrastructure Costs). This module presents results both numerically and graphically. The results achieved using the case studies will be discussed next.

#### 5.1.1 Region of Waterloo

The results for the Region of Waterloo are shown in Figures 5.1 and 5.2. These show that for this Region, for the specified default values, LRT is more cost-effective on an annual basis, for a

study period of 40 years. Even though infrastructure construction cost for LRT is twice as much than BRT's, the difference between labor cost and energy cost makes LRT be the less expensive choice in the long term. Figure 5.2 show that labor, energy and vehicle costs are the ones responsible for this outcome. A large quantity of buses would be required in order to provide enough capacity hence more operators are needed for BRT (since LRT can be coupled), more vehicles are needed as well, and more energy would be consumed. Figure 5.3 shows the frequency (vehicles per hour) for both systems. For this case BRT requires twice as many vehicles as LRT, which results in twice as many operators per hour.

Labor Cost:	\$ 4,907,609.2	\$ 11,163,096.
Energy Cost:	\$ 1,617,569.9	\$ 16,461,148.
Vehicle Cost:	\$ 9,020,465.6	\$ 17,205,875.
Maintenance Cost:	\$ 8,782,555.9	\$ 8,184,246.9
Station Construction Cost:	\$ 753,973.71	\$ 670,198.85
Infrastructure Construction Cost:	\$ 31,470,207.	\$ 15,735,103.
<b>Total Annual Cost:</b>	<b>\$ 56,552,381.</b>	<b>\$ 69,419,669.</b>
	LRT Total Annual Cost	BRT Total Annual Cost

Figure 5.1 Numerical results for Region of Waterloo

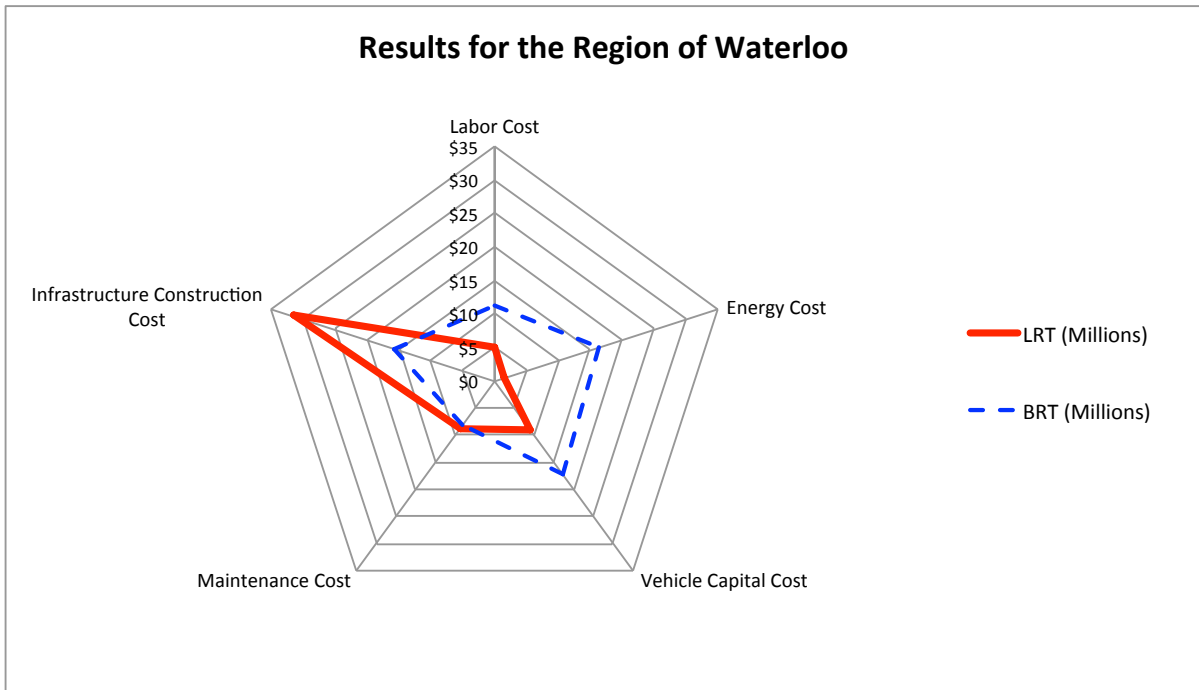


Figure 5.2 Radar graph result for the Region of Waterloo

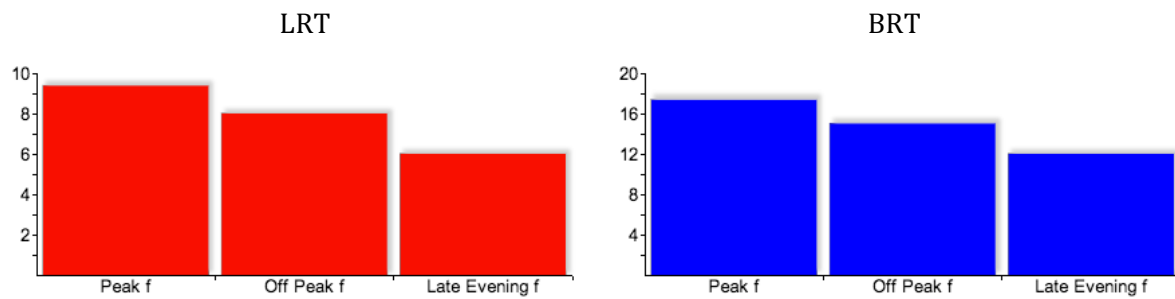


Figure 5.3 Weekday Frequency (vehicles/hr) for Waterloo Region

### 5.1.2 Victoria, BC

The results for the City of Victoria are shown in Figures 5.4 and 5.5. For this city the choice of LRT for the default given values would be the less expensive one. Similar to the Region of Waterloo, the infrastructure construction cost for LRT in Victoria is also twice as much as for BRT. However, other costs, like energy costs, are much higher and cause the total cost for LRT to be more cost effective in the long term, on an annual basis. The main difference in costs,

which can be seen in Figure 5.5, is not only in the infrastructure construction cost, it's also in the Vehicle Capital Cost; BRT would need a higher quantity of vehicles to provide the capacity required, and that will result in the purchase of more vehicles over time. The radar graph also shows that maintenance cost and annualized infrastructure cost per kilometer have a smaller difference between modes than the rest of the costs. This can also be seen in Figure 5.6 where the vehicles needed to operate per hour are twice as much for BRT than for LRT. (Station construction cost is \$0, because for these values this cost is included in the infrastructure construction cost.)

Labor Cost:	\$ 1,559,908.1	\$ 3,613,736.6
Energy Cost:	\$ 519,154.99	\$ 5,183,796.0
Vehicle Cost:	\$ 7,637,705.8	\$ 28,374,240.
Maintenance Cost:	\$ 3,394,858.4	\$ 2,844,750.8
Station Construction Cost:	\$ 0.00	\$ 0.00
Infrastructure Construction Cost:	\$ 46,793,908.	\$ 24,215,029.
<b>Total Annual Cost:</b>	<b>\$ 59,905,535.</b>	<b>\$ 64,231,553.</b>
	LRT Total Annual Cost	BRT Total Annual Cost

Figure 5.4 Numerical results for Victoria



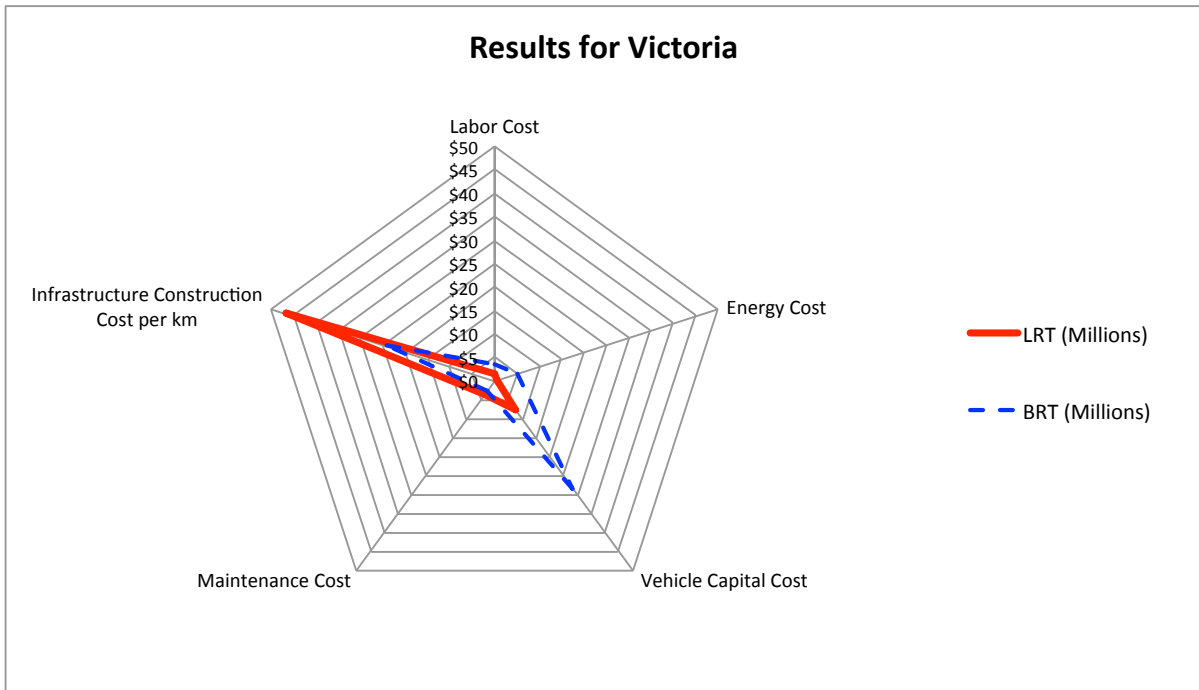


Figure 5.5 Radar graph result for Victoria

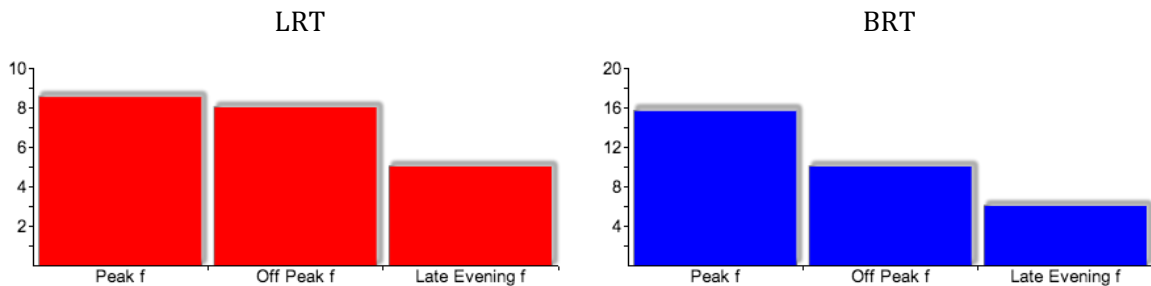


Figure 5.6 Weekday Frequency (vehicles/hr) for Victoria

### 5.1.3 Cleveland, Ohio

The results for the Cleveland system, as shown in Figure 5.7 and Figure 5.8, demonstrate that BRT was the right choice. The model results show that BRT is the less expensive choice for this city, but the only factor that makes this true is the high infrastructure construction costs considered for LRT. With this said, for lower infrastructure construction costs, BRT could become the more expensive choice. Figure 5.9 shows that the main difference in costs is seen

not only in infrastructure costs but also in vehicle costs. BRT vehicle capital cost is almost twice as expensive because, as seen in Figure 5.10, BRT needs twice as much vehicles per hour. The radar graph also shows that maintenance cost is almost equal for both modes, in this case.

Labor Cost:	\$ 899,320.20	\$ 1,797,264.4
Energy Cost:	\$ 594,396.65	\$ 2,103,610.6
Vehicle Cost:	\$ 2,341,851.6	\$ 3,971,454.4
Maintenance Cost:	\$ 2,395,023.8	\$ 2,398,633.3
Station Construction Cost:	\$ 1,690,066.6	\$ 1,690,066.6
Infrastructure Construction Cost:	\$ 32,052,988.	\$ 16,026,494.
<b>Total Annual Cost:</b>	<b>\$ 39,973,647.</b>	<b>\$ 27,987,523.</b>
	LRT Total Annual Cost	BRT Total Annual Cost

Figure 5.7 Numerical results for Cleveland

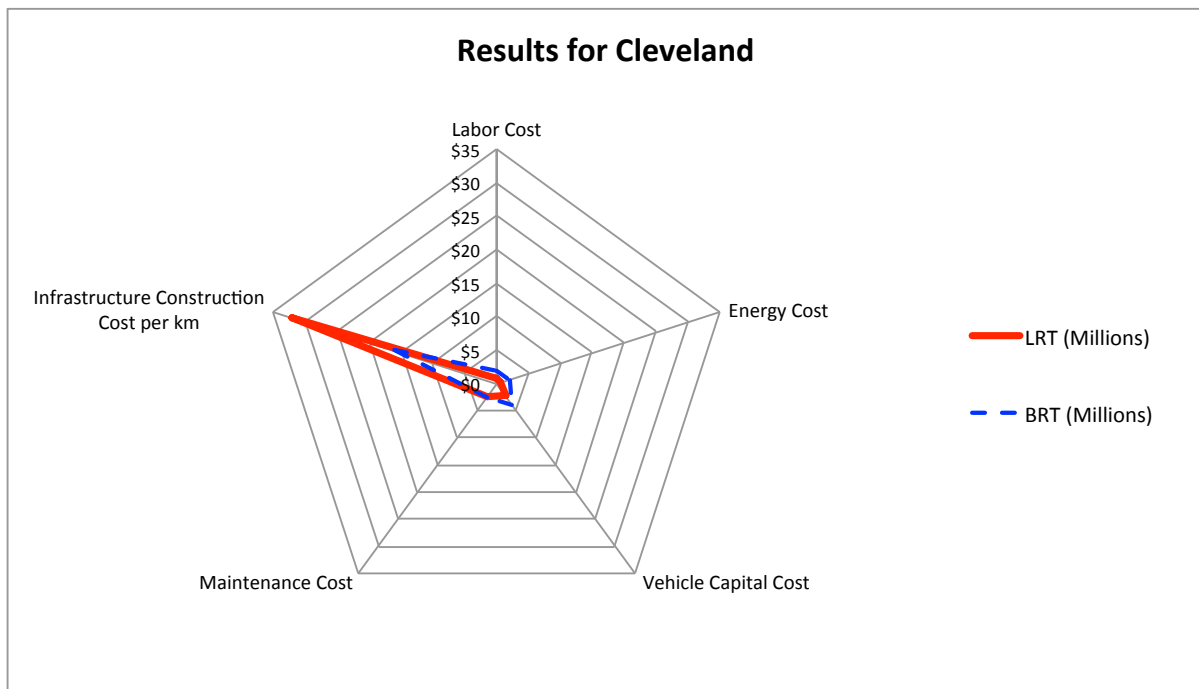


Figure 5.8 Radar graph result for Cleveland

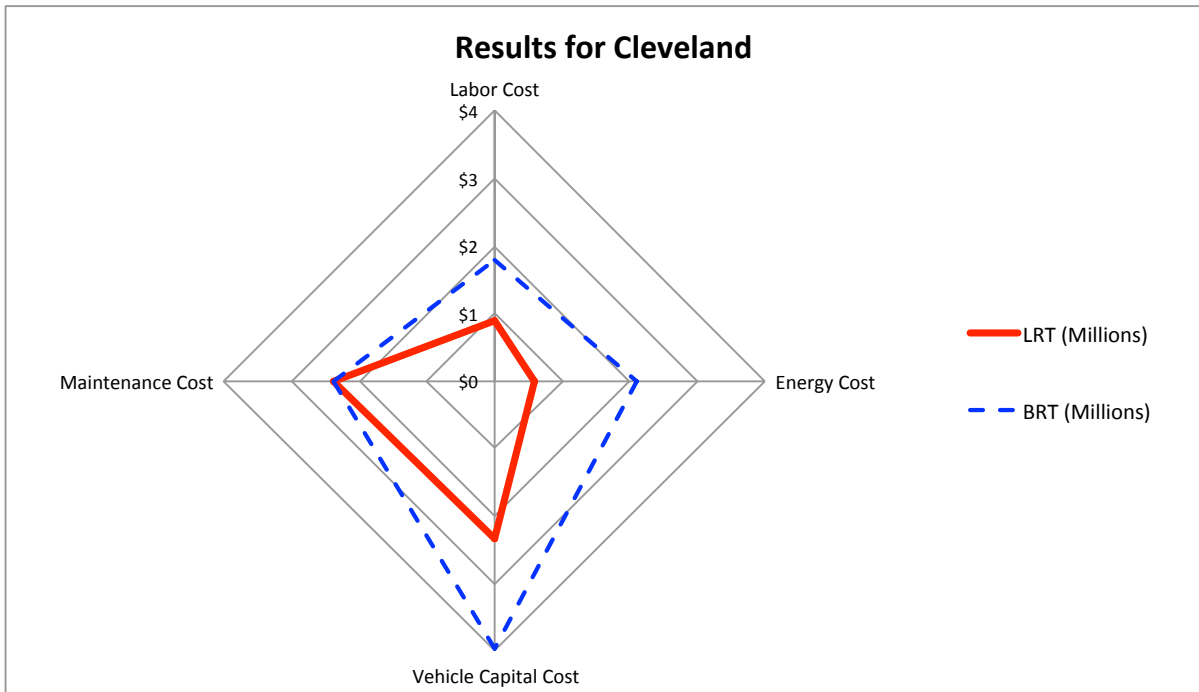


Figure 5.9 Radar graph result for Cleveland without Infrastructure Construction Cost

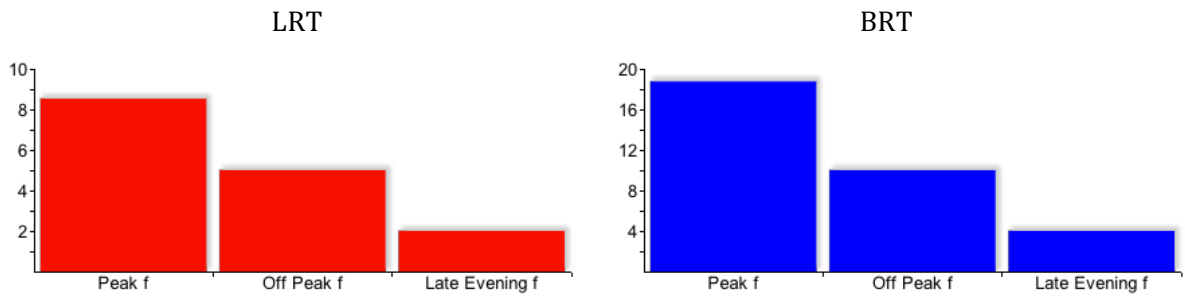


Figure 5.10 Weekday Frequency (vehicles/hr) for Cleveland

### 5.1.4 Mexico City, Mexico

For Mexico City, the difference between the costs for each mode is very substantial as shown in Figures 5.11 and 5.12. BRT is the less expensive option for this city. The main difference in costs for this system lies in the infrastructure costs, these is mainly due to the low labor cost for construction in this city. Large differences are also noticed in labor and vehicle costs. Labor costs are less expensive for LRT since fewer operators are needed because it provides higher

capacity with fewer vehicles. Nevertheless, the vehicle cost for LRT is far more expensive, and therefore offset the labor savings. Figure 5.13 shows the difference in vehicles per hour needed for this system, for both modes. BRT is only more expensive when considering labor costs (because equal labor rates are assumed for both modes) and energy costs. If capital cost for LRT were assumed to be lower then the difference between the costs would be noticeably less. Figure 5.12 shows that for this specific case: when considering both capital costs and maintenance costs BRT is the less expensive mode; when considering only labor and energy costs LRT becomes the less expensive mode.

Labor Cost:	\$ 3,721,727.7	\$ 9,201,680.1
Energy Cost:	\$ 8,203,781.6	\$ 9,889,099.8
Vehicle Cost:	\$ 29,143,042.	\$ 23,016,383.
Maintenance Cost:	\$ 10,367,910.	\$ 6,871,460.3
Station Construction Cost:	\$ 536,159.08	\$ 268,079.54
Infrastructure Construction Cost:	\$ 17,483,448.	\$ 3,496,689.6
<b>Total Annual Cost:</b>	<b>\$ 69,456,069.</b>	<b>\$ 52,743,393.</b>
	LRT Total Annual Cost	BRT Total Annual Cost

Figure 5.11 Numerical results for Mexico City

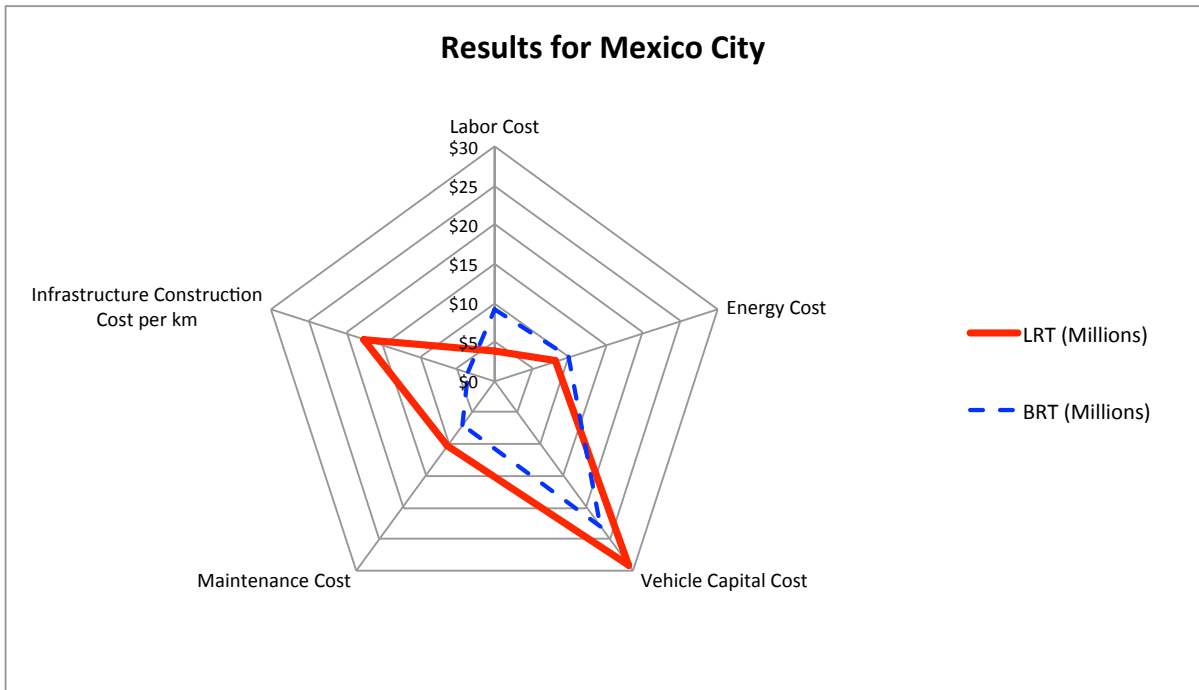


Figure 5.12 Radar graph result for Mexico City

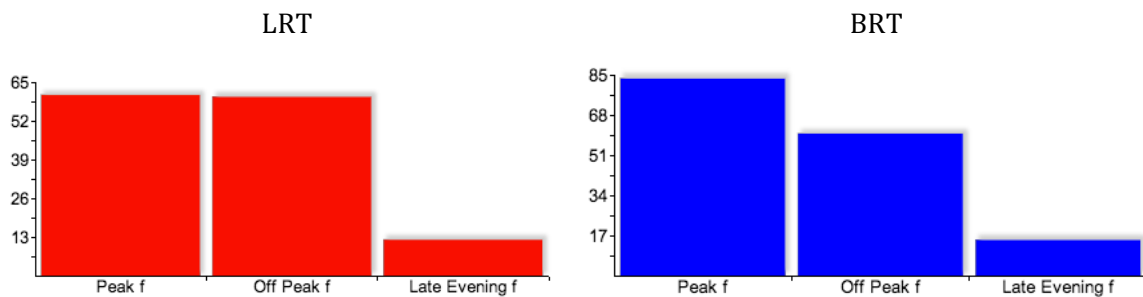


Figure 5.13 Weekday Frequency (vehicles/hr) for Mexico City

The results for this module show the main cost outcomes and where the main difference in these costs occurs. The radar graph helps the analyst visualize these main differences, and compare the costs in respect to each other.

Table 5.1 shows the results for the total annual costs for each case study and illustrates the less expensive modes for each one. These results are consistent with the studies made by each region and with the systems already developed. Waterloo and Victoria chose an LRT as the rapid transit system to be implemented in these regions, while Cleveland and Mexico City have already implemented a BRT system in these cities.

**Table 5.1 Summary of the cost module's results**

City	LRT	BRT
Waterloo	\$57 M	\$69 M
Victoria	\$60 M	\$64 M
Cleveland	\$40 M	\$28 M
Mexico City	\$69 M	\$53 M

## **5.2 Break-Even Point Analysis**

As discussed in Chapter 3, the model developed for this research has the ability to find the economic break-even point of these two transit modes. The break-even point module, as previously discussed, is the second part of the model. This module allows planners and engineers to find the relative domains of demand for which rail and bus are more cost effective. This break-even point is found where both modes have equal total annual costs. This analysis also includes the determination of the sensitivity section which was defined visually by determining where the lines are closer to each other, which means that this area would be more sensitive of changing the preferred mode if changing the parameters. This section will discuss the result obtained from this analysis.

### **5.2.1 Region of Waterloo**

Waterloo Region's estimated MLS is expected to be around 1665 passengers per hour. After obtaining the results from this analysis, it is determined that the break-even point for this region, shown in Figure 5.14, is around 1200 passengers per hour. At this demand both modes would have equal annual costs, and for demands larger than 1450 LRT is the less expensive mode. The domain for BRT is more evident for demands lower than 1000.

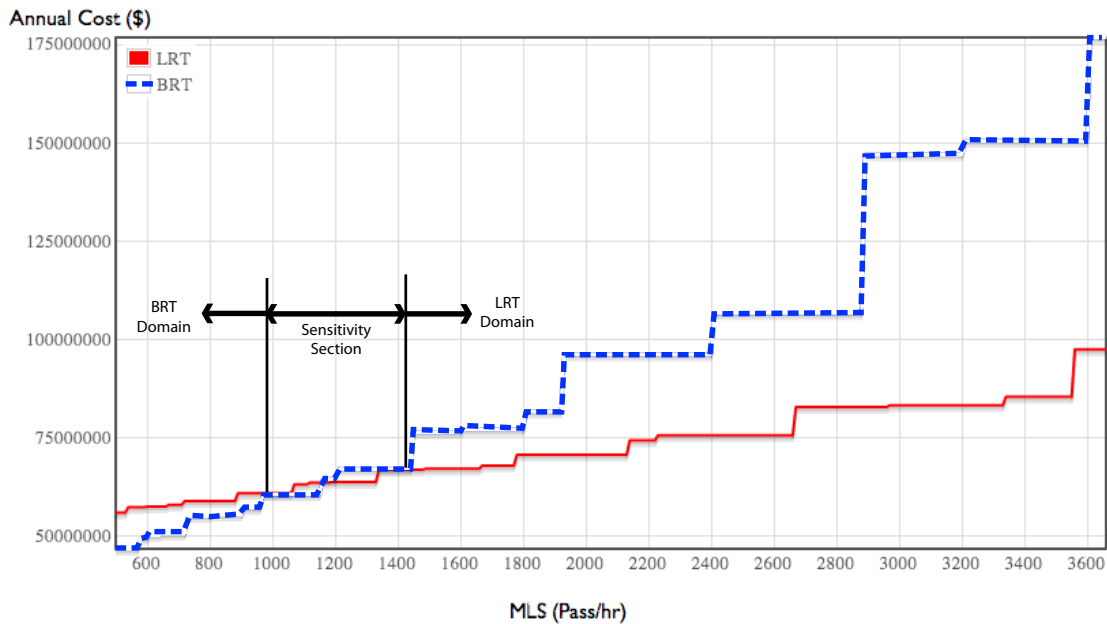


Figure 5.14 Break-even point analysis result for Region of Waterloo

## 5.2.2 Victoria, BC

The City of Victoria estimated an MLS of 1500 passengers per hour. The results obtained in this analysis show that the break-even point between the modes for the default values and parameters is 1450 passengers per hour. In this case BRT domain clearly extends towards demands lower than this point but the sensitivity section for this case goes from around 1200 to around 1900, which means that changes in parameters can cause a change in the preferred mode for these values. The break-even point analysis results are shown in Figure 5.15.

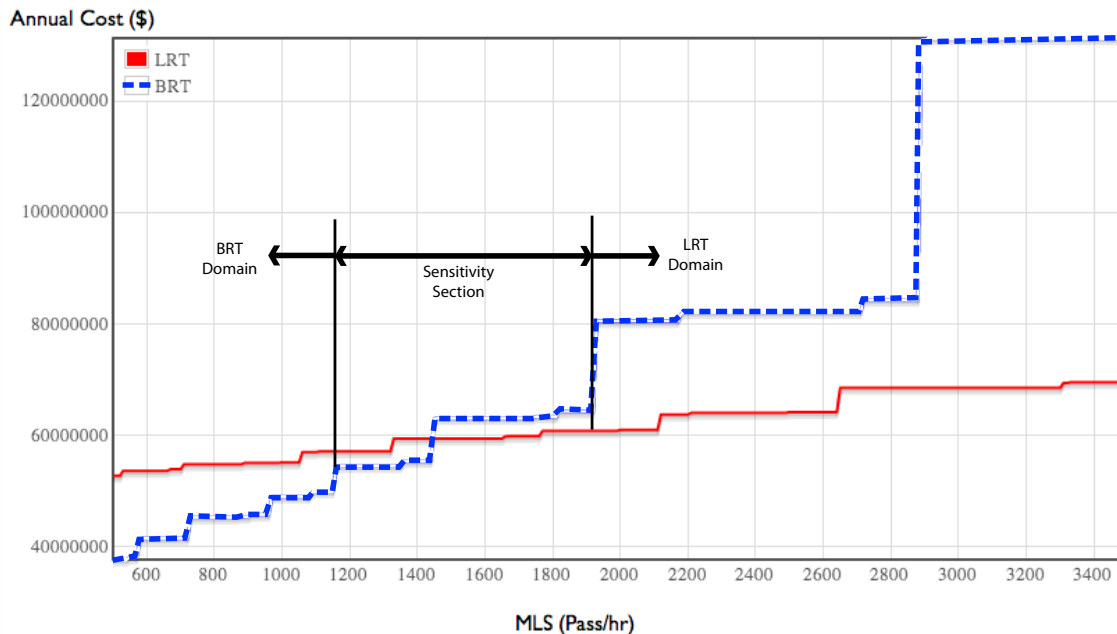


Figure 5.15 Break-even point analysis results for Victoria

### 5.2.3 Cleveland, Ohio

The break-even point analysis for Cleveland shows that, for demands from 600 passengers per hour to even 3400 passengers per hour, BRT would have a clear advantage over LRT, as shown in Figure 5.16. In this case what happens is that BRT is never more expensive than LRT but there would be a demand for which BRT would not have the capacity required to function properly, which was found (by trial and error) to be 4900. When this demand is achieved an upgrade to a higher capacity system (LRT) is needed. This break-even point is never found in this case because infrastructure costs assumed for LRT are very expensive. Even though this is the case, a sensitivity section can be found for demands higher than 2400 because costs get closer together as it can be seen in Figure 5.16. If the infrastructure construction costs for LRT were assumed to be \$5 Million less per km, as an arbitrary example to show the difference, then the outcome for this analysis would be different. This is shown in Figure 5.17, were in this case the MLS\* is found at a demand of 2400, even though the clear domain for LRT would be for demands higher than 3200 passengers per hour. The estimations behind capital costs can affect



the assessment made by planners when choosing a technology, because it is difficult to know if the data used are based on a realistic assessment or a bias in planning.

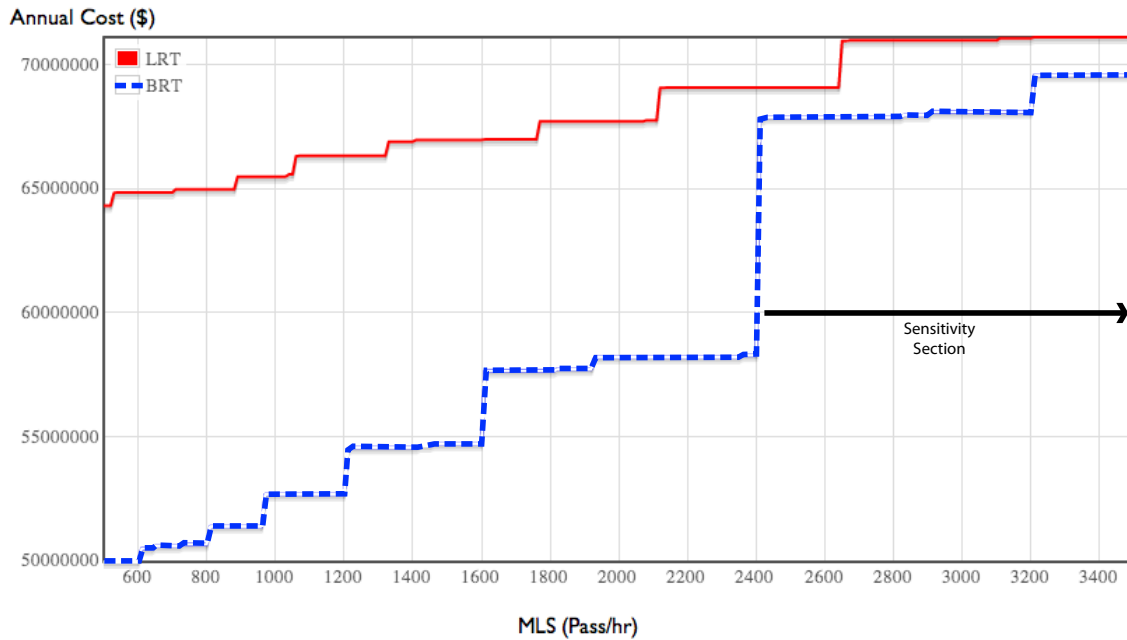


Figure 5.16 Break-even point analysis results for Cleveland

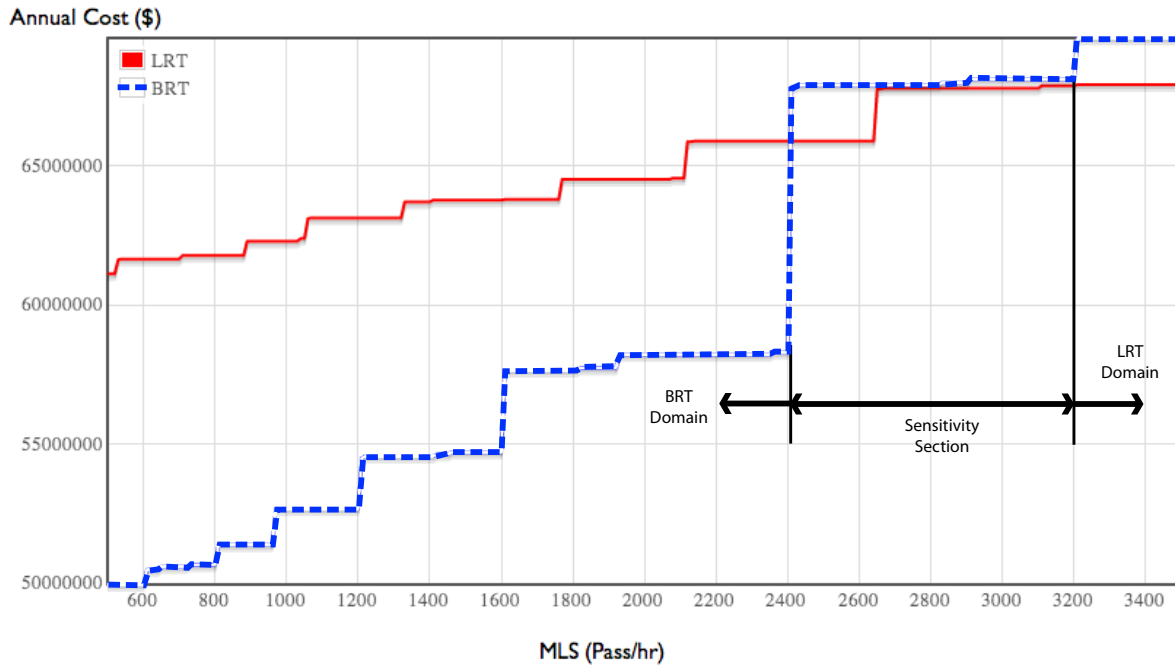


Figure 5.17 Break-even point analysis with modified values for Cleveland

### 5.2.4 Mexico City, Mexico

The case for Mexico City’s break-even point is similar to Cleveland’s. BRT is for many demand levels the less expensive choice. There is also no break-even point for the default values, as shown in Figure 5.18. What would happen in this case is that BRT will require an excessive amount of buses to run creating high volume traffic, which will cause delays, and an upgrade would be needed in order to provide enough capacity. This will happen at an MLS of 15500 passengers per hour. A sensitivity section for this case might be found for demands from 4000 to 6000 where total annual costs slightly converge.

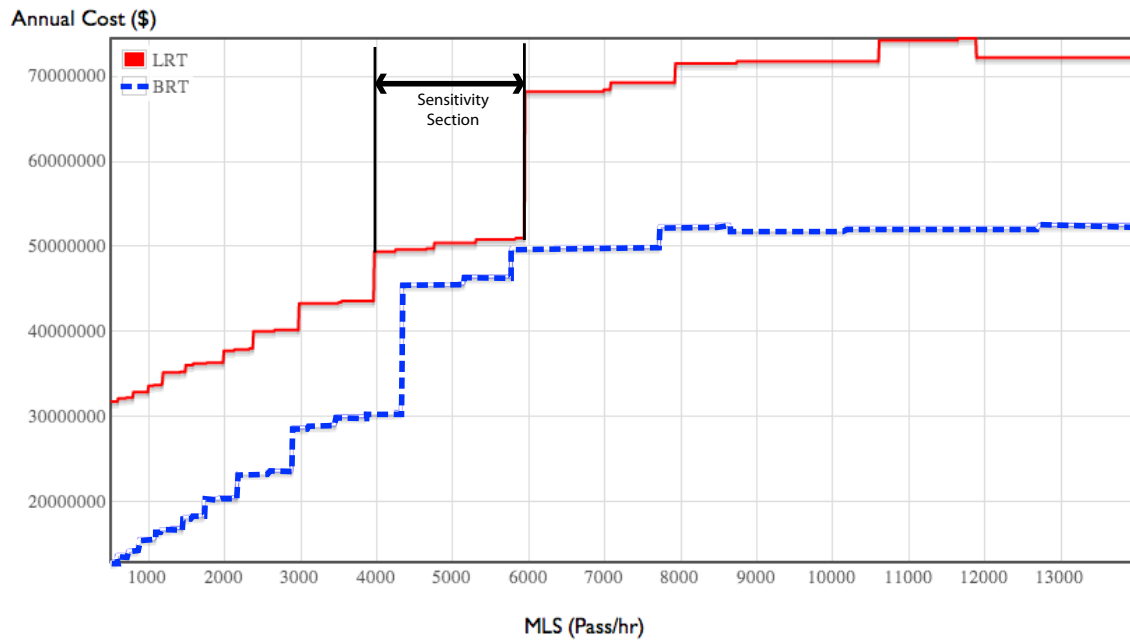


Figure 5.18 Break-even point analysis results for Mexico City

Figure 5.19 show a summary of the break-even points found for each case study.

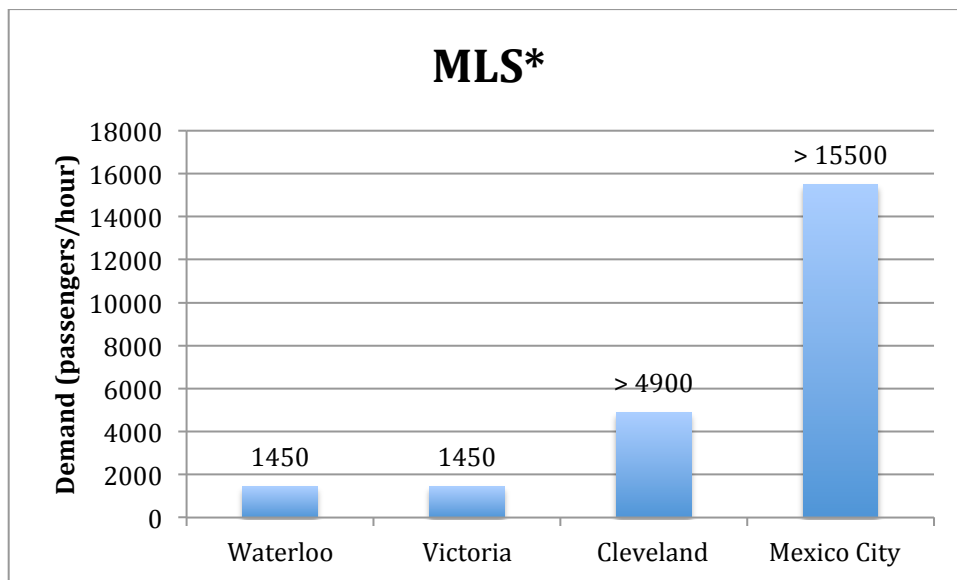


Figure 5.19 Break-even point analysis summary of MLS\* results

Table 5.2 show the clear domains for BRT and LRT for each of the cases previously discussed and also their sensitivity section.

**Table 5.2 Break-even point summary of results**

City	BRT Domain	Sensitivity Section	LRT Domain
Region of Waterloo	0-1000	1000-1450	1450+
Victoria	0-1150	1150-1900	1900+
Cleveland	All visible	2600+	N/A
Mexico City	All visible	4000+	N/A

Figures 5.20 and 5.21 show how the costs for each case increase when increasing the demand. It is noticeable how costs for LRT grow at a lower rate than BRT, especially for the cases of the Region of Waterloo and Victoria. For these two cases, the annual cost for BRT increase at a faster rate than for LRT, for higher demands. This is mainly due to higher labor costs and slower speeds estimated for BRT. High labor costs result on higher operating costs when adding more operators and more vehicles to offer the capacity required. On the other hand, Cleveland shows a higher rate for BRT as well, but it is not as noticeable as the previous cases because higher operating speeds were assumed. Mexico City's case shows how both costs increase at almost the same rate, hence detailing why it is difficult to find the MLS\* for this case. This slow rate is due to the low labor and energy cost rates, which cause the annual costs to also have a low rate when considering higher demands.

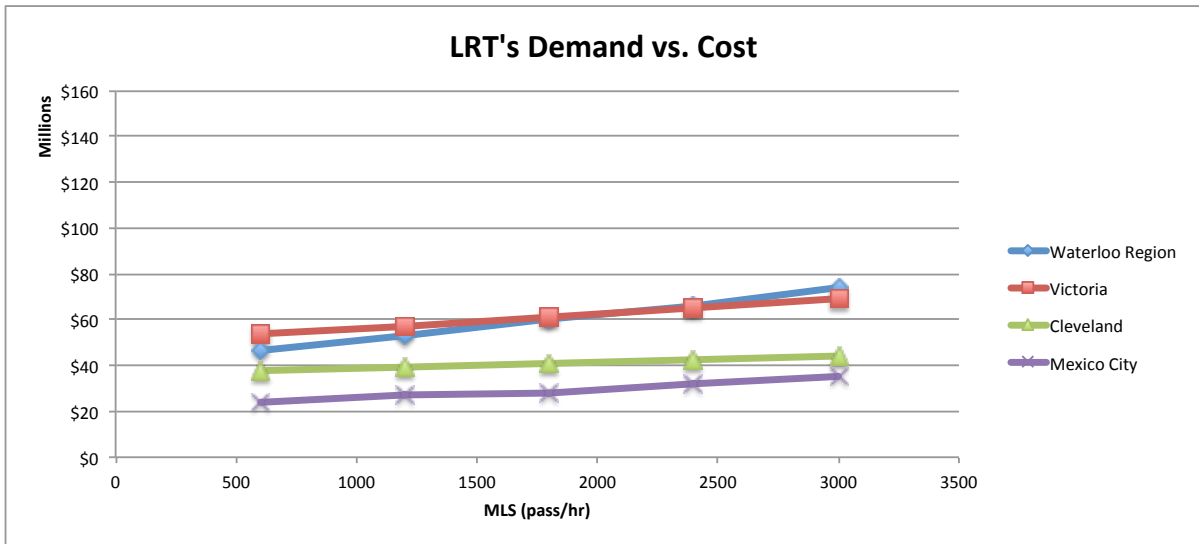


Figure 5.20 LRT Demand vs. Cost for all cases

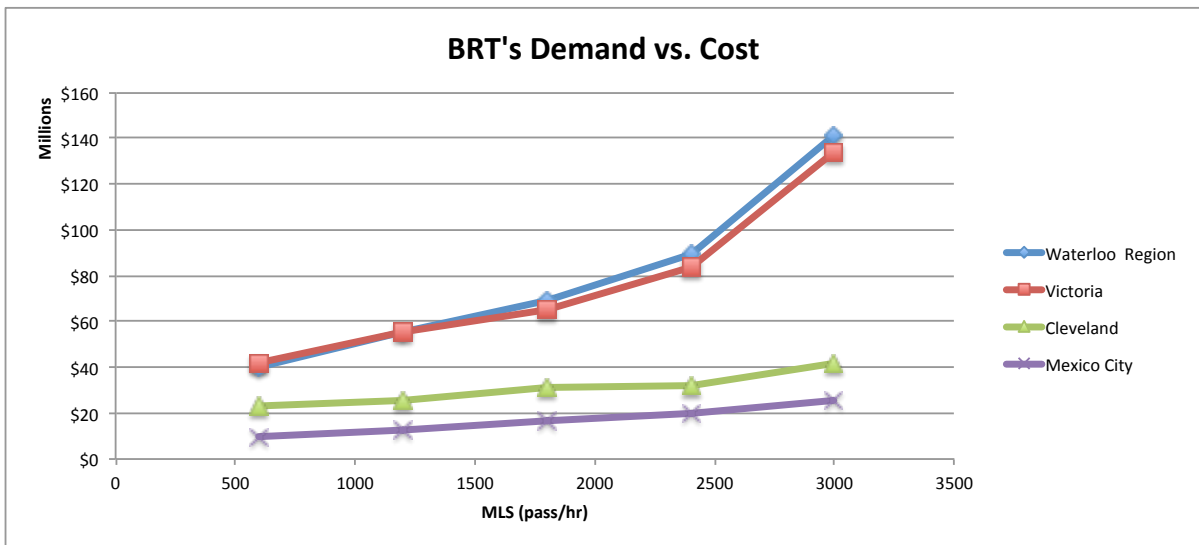


Figure 5.21 BRT Demand vs. Cost for all cases

### 5.3 Sensitivity Analysis

As previously discussed, the model allows the user to test the sensitivity of technology selection to operating cost parameters particularly maintenance, labor and energy costs. The model tests

the sensitivity of inputs in the total operating costs and costs that vary over time, like vehicle costs.

This section reviews the sensitivity analyses made for the case studies. These analyses were made by altering the inputs to see how they affect the outputs of the model, specifically how they affect operating costs. The outputs are shown both numerically and graphically.

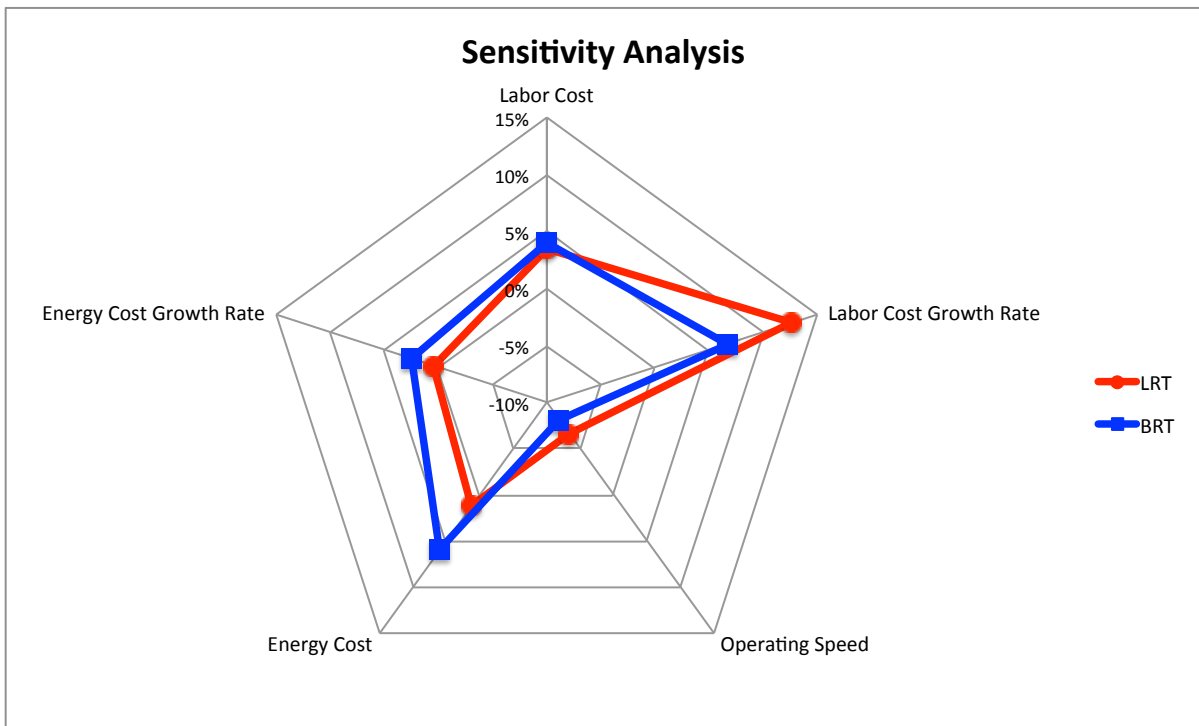
These cases were analyzed using the MLS\* because sensitivity to inputs and parameters become most important for values of demand nearest to this break-even point. For these cases parameters were tested using a 20% change; this number was chosen to demonstrate the sensitivity at a noticeable rate.

### **5.3.1 Region of Waterloo**

The default MLS\* for the Region of Waterloo is around 1000-1200 passengers per hour, as previously mentioned. Table 5.3 shows the percent change of the total operating costs when changing the input displayed. Figure 5.22 shows the graphical results of this analysis. This case shows that for this system LRT is more sensitive to changes in the growth rate for labor costs, while BRT is more sensitive to changes in operating speed, energy costs and growth rate for energy cost. LRT and BRT are both equally sensitive to changes in labor costs and almost equally sensitive to changes in operating speed. BRT is more sensitive on changes related to energy cost. If these changes are applied to the system for this case, considering the demand at the break-even point, LRT becomes the preferred mode, except when altering the operating speed.

**Table 5.3 Numerical results for sensitivity analysis for Region of Waterloo changing each parameter 20%**

Sensitivity Analysis	% Change in total Annual Cost		Comments
	LRT	BRT	
Labor Cost	4%	4%	Equally sensitive; for this change LRT becomes the preferred mode
Labor Cost Growth Rate	13%	7%	LRT is more sensitive; for this change LRT becomes the preferred mode
Operating Speed	-7%	-8%	Almost equally sensitive; No change in the break-even point
Energy Cost	1%	6%	BRT is more sensitive; LRT is almost not sensitive; LRT becomes the preferred mode
Energy Cost Growth Rate	0%	3%	BRT is more sensitive; LRT is not sensitive; LRT becomes the preferred mode



**Figure 5.22 Sensitivity Analysis for Region of Waterloo**

### 5.3.2 Victoria, BC

The break-even point for the systems in Victoria is also 1450 passenger per hour, as previously discussed. Sensitivity analysis numerical results for this case are shown in Table 5.4, and graphical results are displayed in Figure 5.23. In this case both BRT and LRT are most sensitive to changes to their operating speed, BRT reacting the most to this change. For this system the other changes didn't create a large effect on the total operating costs. The only other less noticeable effect is in energy cost for BRT. Even though both systems are most sensitive to operating speed, these changes do not cause a change in the preferred mode, while changes in the other parameters cause LRT to become the preferred mode for the demand found in the MLS\*.

**Table 5.4 Numerical results for sensitivity analysis for Victoria changing each parameter 20%**

Sensitivity Analysis	% Change in total Annual Cost		Comments
	LRT	BRT	
Labor Cost	2%	2%	Equally sensitive; LRT becomes the preferred mode
Labor Cost Growth Rate	2%	1%	LRT is somewhat more sensitive; LRT becomes the preferred mode
Operating Speed	-8%	-11%	BRT is more sensitive; No change in the break-even point
Energy Cost	1%	2%	BRT is somewhat more sensitive; LRT becomes the preferred mode
Energy Cost Growth Rate	0%	1%	LRT is not sensitive; BRT is slightly more sensitive; LRT becomes the preferred mode



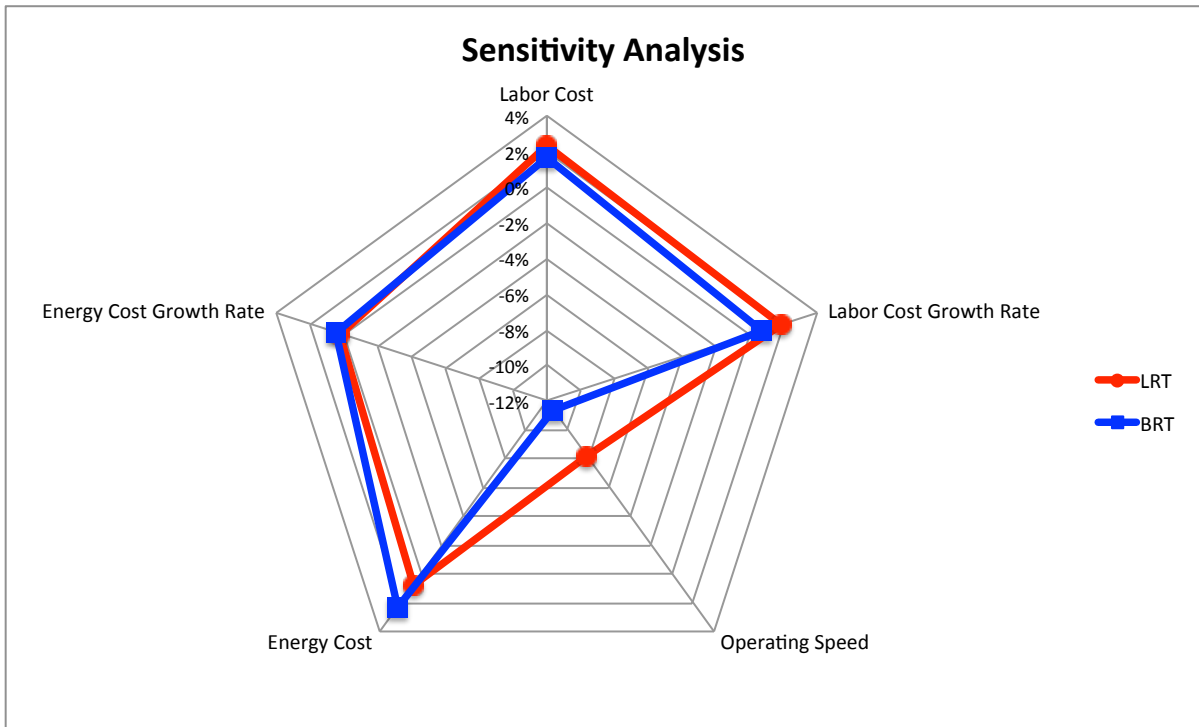


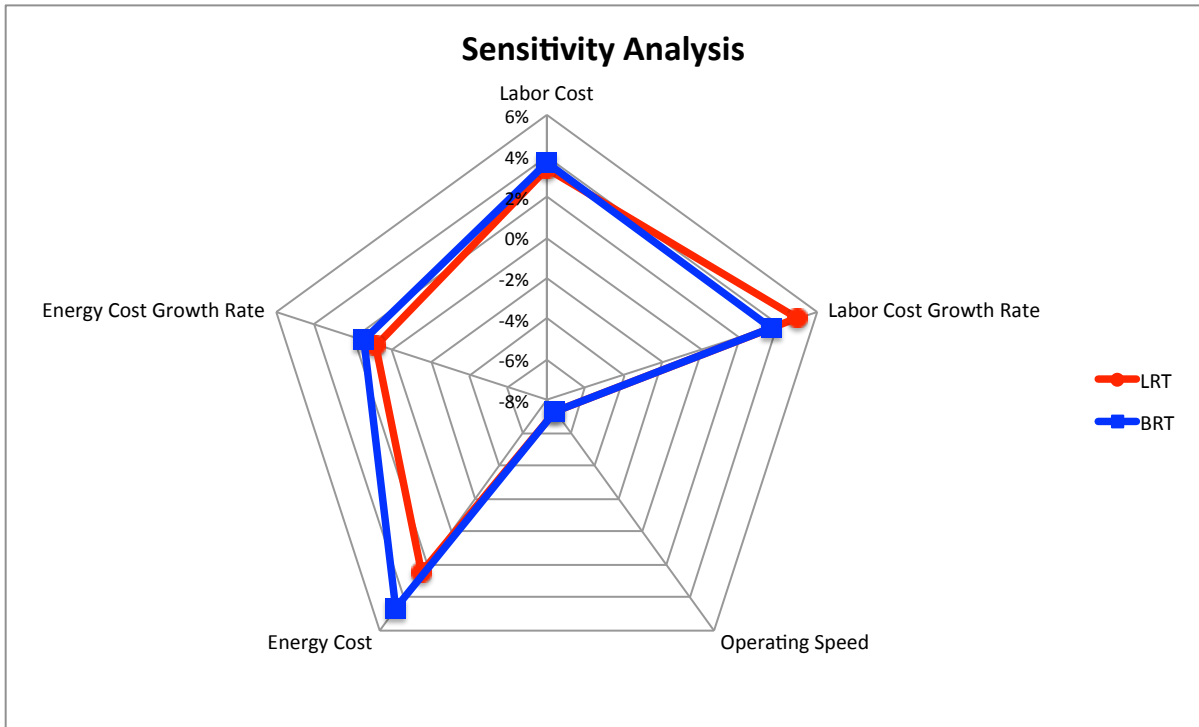
Figure 5.23 Sensitivity Analysis for Victoria

### 5.3.3 Cleveland, Ohio

Since the MLS\* is not found for this system the MLS used for the sensitivity analysis was 4800 passengers per hour, the demand before it exceeds BRT capacity limits. Sensitivity analysis results for this case can be seen numerically in Table 5.5 and graphically in Figure 5.24. As it can be seen both modes would be most sensitive to operating speed being affected equally for this demand. A bit less than to operating speed, LRT would be most sensitive to the growth rate of labor cost while BRT would be most sensitive to energy cost. For all of these changes BRT remains the preferred mode.

**Table 5.5 Numerical results for sensitivity analysis for Cleveland changing each parameter 20%**

Sensitivity Analysis	% Change in total Annual Cost		Comments
	LRT	BRT	
Labor Cost	3%	4%	BRT is slightly more sensitive; BRT remains the preferred mode
Labor Cost Growth Rate	5%	4%	LRT is slightly more sensitive; BRT remains the preferred mode
Operating Speed	-7%	-7%	Equally sensitive; BRT remains the preferred mode
Energy Cost	2%	5%	BRT is more sensitive; BRT remains the preferred mode
Energy Cost Growth Rate	1%	1%	Equally sensitive; almost not sensitive; BRT remains the preferred mode



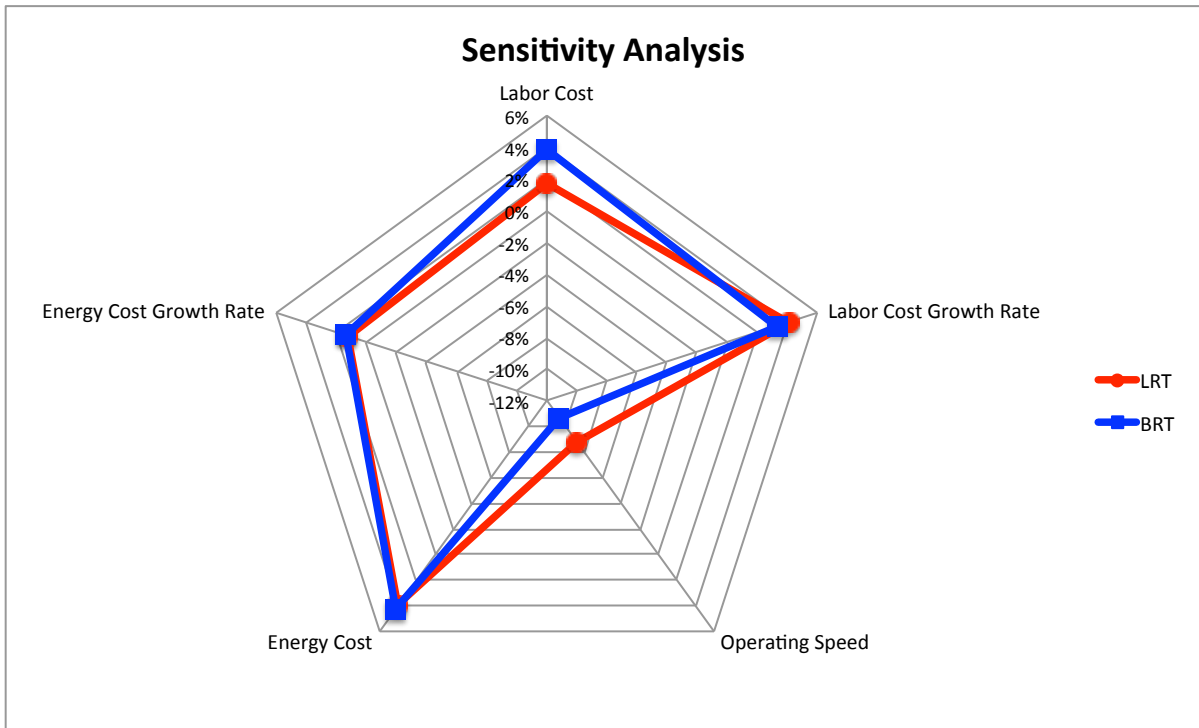
**Figure 5.24 Sensitivity Analysis for Cleveland**

### 5.3.4 Mexico City, Mexico

Mexico City’s MLS\* was also not found, so the existing MLS was used. Results for this case are shown in Table 5.6 and Figure 5.25. The results for this case show that BRT would be more sensitive to changes in labor costs and operating speed than LRT, on the other hand LRT would be more sensitive to changes in the growth rate for labor costs. For all these changes BRT remains the preferred mode.

**Table 5.6 Numerical results for sensitivity analysis for Mexico City changing each parameter 20%**

Sensitivity Analysis	% Change in total Annual Cost		Comments
	LRT	BRT	
Labor Cost	2%	4%	BRT is more sensitive
Labor Cost Growth Rate	4%	3%	LRT is slightly more sensitive
Operating Speed	-9%	-11%	BRT is more sensitive
Energy Cost	4%	4%	Equally sensitive
Energy Cost Growth Rate	1%	1%	Equally sensitive



**Figure 5.25 Sensitivity Analysis for Mexico City**

## 5.4 Emissions Module

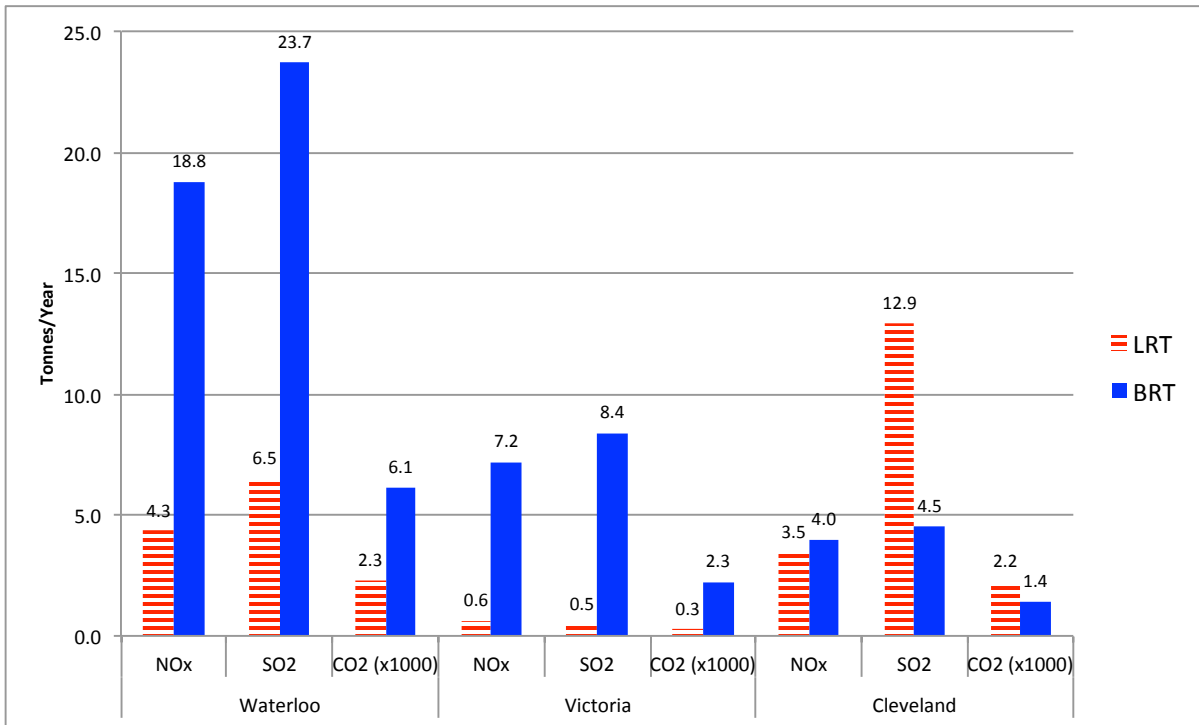
The emissions module obtains an estimate of the annual emissions for three different pollutants (CO<sub>2</sub>, NO<sub>x</sub> and SO<sub>2</sub>) for both modes using the emission rates based on geographic location (to obtain energy sources) and the annual energy consumption.

The results for the emissions module apply only to USA and Canadian cities; hence Mexico City was not included in this analysis. Figure 5.26 shows the results in tonnes for each pollutant.

Waterloo	Victoria	Cleveland
<b>LRT Emissions:</b>	<b>LRT Emissions:</b>	<b>LRT Emissions:</b>
NO <sub>x</sub> (t)= 4.26	NO <sub>x</sub> (t)= 0.63	NO <sub>x</sub> (t)= 3.45
SO <sub>2</sub> (t)= 6.39	SO <sub>2</sub> (t)= 0.48	SO <sub>2</sub> (t)= 12.91
CO <sub>2</sub> (t)= 2262.99	CO <sub>2</sub> (t)= 271.59	CO <sub>2</sub> (t)= 2235.58
<b>BRT Emissions:</b>	<b>BRT Emissions:</b>	<b>BRT Emissions:</b>
NO <sub>x</sub> (t)= 18.70	NO <sub>x</sub> (t)= 7.20	NO <sub>x</sub> (t)= 4.00
SO <sub>2</sub> (t)= 23.60	SO <sub>2</sub> (t)= 8.40	SO <sub>2</sub> (t)= 4.51
CO <sub>2</sub> (t)= 6100.09	CO <sub>2</sub> (t)= 2250.14	CO <sub>2</sub> (t)= 1426.22

Figure 5.26 Results for the Emissions Module

Figure 5.27 presents the results from the emissions module graphically. These numbers indicate that for Waterloo and Victoria emissions for BRT would be greater than those for LRT, while for Cleveland mixed results were obtained. BRT emissions in Cleveland for SO<sub>2</sub> and CO<sub>2</sub> are less than for LRT, but for NO<sub>x</sub> emissions would be higher. This is essentially because the main energy source for electricity in Cleveland is coal, while for Victoria and Waterloo is hydro.



**Figure 5.27 Emissions module results**

Although the economic aspect of taxing emissions is not included within the model a brief analysis was made for this research. If carbon emissions were taxed for these three cities the results would be as shown in Figure 5.28. These results were obtained assuming a tax of \$15 per tonne, as an example. This indicates the effect these emissions could have when considering economic factors. With these results, it can be concluded that even when taxing the emissions, the differences are not enough to change the preferred technology.

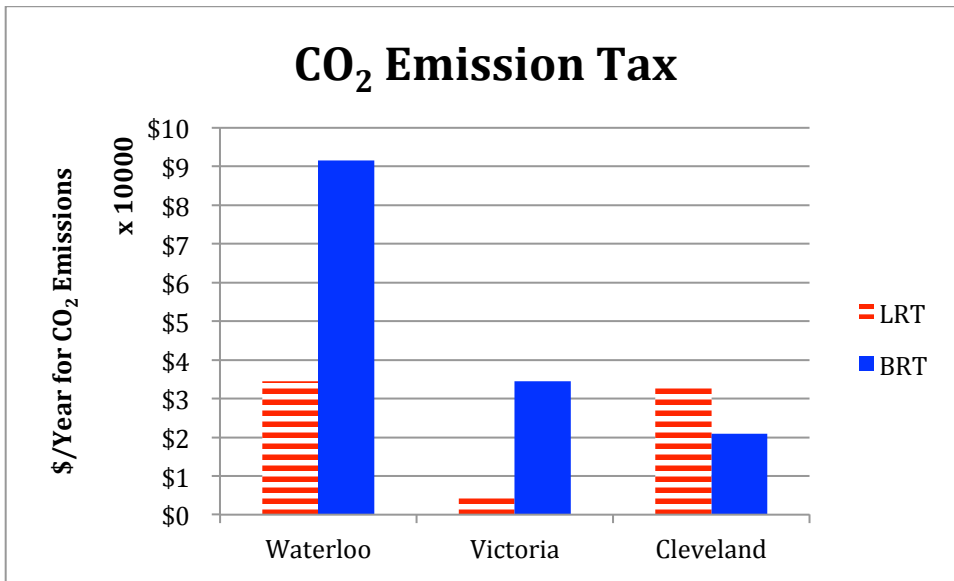


Figure 5.28 CO<sub>2</sub> Emission Tax Example

Emissions for the other pollutants can be assigned an economic factor if the system is implemented in cities with emission trading programs. The addition of this function can be considered for future research.

## 5.5 Summary

The application of the model on technology selection for the four case studies previously introduced in Chapter 4 was discussed and reviewed in this chapter. A detailed analysis of the results of each module inside the model was given including: a detailed cost estimation of both modes, break-even point determination, an analysis of the sensitivity of inputs to the total operating costs and finally the estimation of annual emissions. These results showed how the model developed for this research can be used as a tool by planners and engineers in the decision making process. Table 5.7 shows a summary of the key results.

**Table 5.7 Summary table of key results**

	Region of Waterloo, ON	Victoria, BC	Cleveland, OH	Mexico City, Mexico
Cost Module (Preferred mode)	LRT	LRT	BRT	BRT
Break-even point (passengers/hour)	1200	1500	Not defined	Not defined
Sensitivity Section	1000-1450	1150-1900	2600+	4000+
Sensitivity Analysis	LRT: Most sensitive to labor cost growth rate  BRT: Most sensitive to energy cost	Both modes are most sensitive to operating speed than other parameters, but are equally sensitive to it	LRT: Most sensitive to operating speed  BRT: Most sensitive to energy cost	Both modes are most sensitive to operating speed than other parameters, but are equally sensitive to it
Emissions Module	LRT: Cleaner for all emissions	LRT: Cleaner for all emissions	LRT: Cleaner for NO <sub>x</sub>  BRT: Cleaner for SO <sub>2</sub> and CO <sub>2</sub>	N/A

# Chapter 6

## Conclusions and Future Research

### 6.1 Conclusions

The main goal of this research was to develop an easy-to-use web-based, accessible tool that assists in the decision making process behind transit technology selection. The objectives of this research, which included: obtaining annual costs for the transit modes under evaluation, finding the most appropriate transit mode for a specific scenario, finding the demand at which both transit modes have the same annual costs, testing the sensitivity that outputs have to inputs, finding annual emissions produced by both modes, and showing results that are visual and easy to understand, were achieved by the development of this model.

The literature reviewed in this thesis demonstrated the steps behind technology selection and also summarized the key social and political issues. The model developed for this research can assist in this process by providing a thorough cost estimation for both modes being compared so that the analyst can have a higher probability of choosing the appropriate technology that meets the city's requirements. The model computes life cycle costs for two technologies based upon user-specified system and operating data. It allows the user to test the sensitivity of technology selection to operating costs parameters. In addition, it finds the economic break-even point of the two technologies to allow planners and engineers to determine the relative domains of demand for which rail and bus are more cost effective.

The model also finds environmental impacts, as quantity of pollutants produced by both modes. For this analysis, spatial information on energy sources is used to generate estimates of commonly produced airborne contaminants.

The results of the analysis made to four case studies showed how the model can be used in the technology selection process. It helps the user find the mode with the best set of attributes



considering investment and operating costs and environmental impacts. In the Cost Module, it was found that, for the Region of Waterloo and Victoria, BC, LRT would be the less expensive mode in an annual basis, while, for Cleveland, OH and Mexico City, BRT would be the less expensive mode. The break-even point analysis concluded with three main outcomes: for the Region of Waterloo this point would be 1200 pass/hr and for the City of Victoria it would be 1500 pass/hr, which is less than the projected ridership for both cases; and for the other two cases (Cleveland and Mexico City) this point was not found for the stated scenario. The findings in the emissions module were the following: for the Region of Waterloo and Victoria LRT would be the cleaner mode for all emissions; for Cleveland LRT would be the cleaner mode when considering  $\text{NO}_x$ , but BRT would be the cleaner mode for  $\text{SO}_2$  and  $\text{CO}_2$ .

## **6.2 Transferability and Limitations**

### **6.2.1 Transferability**

The main goal of this research was to develop a model that assists planners and engineers in the decision making process behind transit technology selection. This model was developed to be easily transferable and accessible to consulting and governmental transit agencies. The data required to use this model is readily available by these agencies and default values are provided for use when these data is not complete. Model accessibility made even easier this transferability when migrating the model to the web.

### **6.2.2 Limitations**

The low level of expertise in the coding was the main limitation to the development of this model. A higher level of expertise in JavaScript and HTML would've result perhaps in a more complete emissions module and even more precise graphical results. For example, being able to change easily the scale of the graphs, and change the format of the graph results to a more detailed and more visual result. Another limitation for the development of the model in this thesis includes the scarce data available to develop the emissions module. A more complete

emissions module would've been easier to develop if data was readily available for this kind of use, and if an advanced expertise in the two languages applied was used to develop its code.

## **6.3 Future Research**

The model developed for this research aimed to help decision makers in the technology selection process, specifically between the technologies of LRT and BRT. This is mainly because this research is focused on systems that can be implemented in mid-sized cities. Future research can be conducted in adding more technologies into the comparison made in the model making the model functional for smaller and/or larger cities.

Further investigation can also be applied in the emissions module creating a larger database to make this module capable of obtaining results in a global scale. The addition of other significant pollutants in the emissions module could also be considered for future research. In addition, the analyst location can be determined based on the IP address when accessing the web-based model. This location information can then be used to populate the model with default values for operating costs and parameters that are derived from local data. Finally, a more rigorous approach can be given to the emissions module.

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## Appendix A

### Formula Derivation

#### **Total Annual Labor Cost Formulation**

The total annual labor cost ( $LC$ ) can be written as:

$$LC = LR * AOH \quad (\text{Eq. A-1})$$

where  $AOH$  represents the annual operator hours considering all demand periods and  $LR$  represents the labor wages.

$AOH$  can also be expressed as:

$$AOH = \text{hours}_i * N \quad (\text{Eq. A-2})$$

where  $N$  denotes the vehicles in use and is found by dividing the cycle time,  $T$ , by the headway,  $h$ , as seen in Eq. 3.9:

$$N = \left[ \frac{T}{h} \right]^+$$

Cycle time is found by Eq. 3.8:

$$T = T_o + 2t_t$$

where  $T_o$  is the operating time found by Eq. 3.7:

$$T_o = \frac{120L}{v_o}$$

and  $t_t$  is the terminal time, which is obtained as an input;

and headway is a function of the frequency,  $f$ , as shown in Eq. 3.6:

$$h = \frac{60}{f}$$

frequency is found by dividing the Maximum Load Section ( $MLS$ ) by the capacity offered ( $C$ ), using Eq. 3.5:

$$f = \frac{MLS_i}{C}$$

$MLS$  in this equations is found using Eq. 3.1:

$$MLS_i = \beta \cdot MLS$$

where  $\beta$  is the weight applied to the demand and  $MLS$  is obtained from the inputs;

and the capacity offered is obtained by multiplying the offered vehicle capacity,  $c$ , by the number of vehicles,  $n$ , as shown in Eq. 3.4:

$$C = c \cdot n$$

the offered vehicle capacity is found using Eq. 3.2:

$$c = c_v \cdot \alpha$$

where both  $c_v$  and  $\alpha$  are obtained from the inputs.

Substituting Eq. 3.2 into Eq. 3.4 we obtain:

$$C = c_v \cdot \alpha \cdot n \quad (\text{Eq. A-3})$$

and then substituting Eq. A-3 and Eq. 3.1 into Eq. 3.5 we obtain the following:

$$f = \frac{\beta \cdot MLS}{c_v \cdot \alpha \cdot n} \quad (\text{Eq. A-4})$$

Eq. A-4 is then substituted in Eq. 3.6,

$$h = 60 \frac{c_v \cdot \alpha \cdot n}{\beta \cdot MLS_i} \quad (\text{Eq. A-5})$$

Eq. A-5, Eq. 3.7 and Eq. 3.8 and are then substituted into Eq. 3.9, to obtain:

$$N = \left[ \left( \frac{120L}{v_o} + 2t_t \right) \frac{\beta \cdot MLS_i}{60 \cdot c_v \cdot \alpha \cdot n} \right]^+ \quad (\text{Eq. A-6})$$

Then substituting Eq. A-6 into Eq. A-2 we obtain:

$$AOH = hours_i * \left[ \left( \frac{60L}{v_o} + t_t \right) \frac{\beta \cdot MLS_i}{30 \cdot c_v \cdot \alpha \cdot n} \right]^+ \quad (\text{Eq. A-7})$$

with this equation we can obtain the annual total labor costs substituting Eq. A-7 into Eq. A-1,

$$LC = LR * \sum_i hours_i * \left[ \left( \frac{60L}{v_o} + t_t \right) \frac{\beta \cdot MLS_i}{30 \cdot c_v \cdot \alpha \cdot n} \right]^+ \quad (\text{Eq. 3.14})$$

## Total Annual Energy Cost Formulation

The total annual energy cost ( $EC$ ) can be written as:

$$EC = ER * ECR * AVK \quad (\text{Eq. A-8})$$

where  $AVK$  represents the annual vehicle-kilometers considering all demand periods,  $ER$  denotes the energy cost rates and  $ECR$  represents the energy consumption rate.

$AVK$  can also be expressed as:

$$AVK = vkm_i * days \quad (\text{Eq. A-9})$$

where  $vkm$  is the vehicle-kilometers per period found by:

$$vkm_i = \sum_i n \cdot f \cdot 2 \cdot L \cdot hours_i \quad (\text{Eq. A-10})$$

where  $n$  represents the vehicles per transit unit,  $f$  denotes the frequency,  $L$  represents the length of the alignment (which is an input), and the  $hours_i$  represent the hours per period, as inputted by the user.

Then substituting Eq. A-4 into Eq. A-10 we obtain:

$$vkm_i = \sum_i n \cdot \frac{\beta \cdot MLS}{c_v \cdot \alpha \cdot n} \cdot 2 \cdot L \cdot hours_i \quad (\text{Eq. A-11})$$

and substituting Eq. A-11 into Eq. A-9 we achieve:

$$AVK = \sum_i \frac{\beta \cdot MLS}{c_v \cdot \alpha} \cdot 2 \cdot L \cdot hours_i * days \quad (\text{Eq. A-12})$$

with this equation we can obtain the annual total labor costs substituting Eq. A-12 into Eq. A-8,

$$EC = ER * ECR * \sum_i \frac{\beta \cdot MLS_i}{c_v \cdot \alpha} \cdot 2 \cdot L \cdot hours_i * days \quad (\text{Eq. 3.15})$$

## Total Annual Vehicle Cost Formulation

The total annual vehicle cost ( $VC$ ) can be written as:

$$VC = VCC * MVS * \frac{P}{SL} \quad (\text{Eq. A-13})$$

where  $VCC$  represents the vehicle capital costs,  $MVS$  represents the maximum vehicle service,  $P$  denotes the period of study and  $SL$  represents the service life. The period and service life are inputs in the model.

$MVS$  can also be expressed as:

$$MVS = [N_{max} \cdot n]^+ \quad (\text{Eq. A-14})$$

where  $n$  represents the vehicles per transit unit and  $N$  represents the maximum transit units needed.

Substituting Eq. 3.7 and 3.8 into Eq. A-14 we obtain the following:

$$MVS = \left[ \left[ \left( \frac{60L}{v_o} + t_t \right) \frac{\beta \cdot MLS_{max}}{30 \cdot c_v \cdot \alpha} \right]^+ \right]^+ \quad (\text{Eq. A-15})$$

Then, Eq. A-15 is substituted into Eq. A-13 to find  $VC$ :

$$VC = VCC * \left[ \left[ \left( \frac{60L}{v_o} + t_t \right) \frac{\beta \cdot MLS_{max}}{30 \cdot c_v \cdot \alpha} \right]^+ \right]^+ * \frac{P}{SL} \quad (\text{Eq. 3.16})$$

## Total Annual Maintenance Cost Formulation

The total annual maintenance cost ( $MC$ ) can be written as:

$$MC = VMR * AVK + IMR * L \quad (\text{Eq. A-16})$$

where  $AVK$  represents the annual vehicle-kilometers considering all demand periods,  $VMR$  denotes the vehicle maintenance cost rates,  $IMR$  represents the infrastructure maintenance cost rate, and  $L$ , denotes the length of the alignment. These last three are acquired as inputs.

$AVK$  was previously defined in Eq. A-12:

$$AVK = \sum_i \frac{\beta \cdot MLS_i}{c_v \cdot \alpha} \cdot 2 \cdot L \cdot hours_i * days \quad (\text{Eq. A-12})$$

with this equation we can obtain the annual total maintenance costs substituting Eq. A-12 into Eq. A-16,

$$MC = VMR * \left[ \sum_i \frac{\beta \cdot MLS_i}{c_v \cdot \alpha} \cdot 2 \cdot L \cdot hours_i \right] * days + (IMR * L) \quad (\text{Eq. 3.17})$$

## Appendix B

### Website Code

```
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN" "http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">
<head>
<meta content="text/html; charset=windows-1252" http-equiv="Content-Type" />
<!--Code for graph (libraries)-->
<script type="text/javascript" src="http://apis.google.com/js/plusone.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.common.core.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.common.dynamic.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.common.effects.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.common.tooltips.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.common.key.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.bar.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.radar.js"></script>
<script src="http://www.civil.uwaterloo.ca/dsantiag/RGraph2_2012-03-28-stable/RGraph/libraries/RGraph.line.js"></script>
<script type="text/javascript" src="http://www.civil.uwaterloo.ca/dsantiag/prototype.flotr-0.2.0-alpha/flotr-0.2.0-alpha/flotr/lib/excanvas.js"></script>
<script type="text/javascript" src="http://www.civil.uwaterloo.ca/dsantiag/prototype.flotr-0.2.0-alpha/flotr-0.2.0-alpha/flotr/lib/prototype-1.6.0.2.js"></script>
<script type="text/javascript" src="http://www.civil.uwaterloo.ca/dsantiag/prototype.flotr-0.2.0-alpha/flotr-0.2.0-alpha/flotr/flotr-0.2.0-alpha.js"></script>
<!-- Radar and bar graphs were made thanks to RGraph and Break-even point graph was made using the line graph provided by flotr-->

<title>Model</title>
<script type="text/javascript">
function LRTCcapacity()
{
var a = document.frmOne.LRTcv.value;
var b = document.frmOne.Alpha.value;
a = Number(a); //cv
b = Number(b); //alpha
c = (a * b); //capacity offered
return c;
}

function LRTMLS()
{
var a = document.frmOne.LRTMLS.value;
a=Number(a); //MLS
return a;
}
}
```

```

function LRTvehTU()
{
if(document.frmOne.coupling.checked==true)
{
if(LRTMLS()/LRTCcapacity()>12)
{
veh=2;
}
else
{
veh=1;
}
}
else veh=1;
return veh;
}

function LRTTUcap()
{
var tucap;
tucap = LRTCcapacity()*LRTvehTU();
return tucap;
}

function LRTFrequency()
{
var f;
f = (LRTMLS()/LRTTUcap());
if(f<2)
{
f=2;
}
return f;
}

function LRTHeadway()
{
var h;
h = Math.floor(60/LRTFrequency());
if(60%h==0)
{
h=h;
}
else
{
while(60%h!=0)
{h = (h-0.5);}
}
return h
}

function LRToperatingTime()
{
a = document.frmOne.LRTvo.value;
b = document.frmOne.LRTl.value;

```

```

a = Number(a); //Vo
b = Number(b); //L
c = (120*(b/a)); //To
return c;
}

function LRTCycleTime()
{
d = document.frmOne.LRTtt.value;
d = Number(d); //tt
rt= (LRTOperatingTime() + (2*d)); //T
return rt;
}

function LRTN()
{
var N =(LRTCycleTime()/LRTHeadway()); //N peak hour
N = Math.ceil(N);
return N;
}

function LRTVehPeak()
{
vehs = Math.round(LRTN()*LRTvehTU()); //vehicles needed in peak hour
return vehs;
}

function LRTPeakTc()
{
nTc=(LRTN()*LRTHeadway()); //New Cycle Timepeak hour
return nTc;
}

function LRTPeaktt()
{
optt=((LRTPeakTc()-LRTOperatingTime())/2); //New terminal time peak hour
return optt;
}

function LRTTotalVehPeak()
{
a = document.frmOne.LRTsr.value;
a = Number(a);
a = a/100;
vehs = ((1+a)*LRTVehPeak()) //Total Vehicles Required for Both Peaks
vehs = Math.ceil(vehs);
return vehs;
}

function LRTNonPeakVeh()
{
var a = document.frmOne.LRTmlsratio2.value;
var b; //Number of Veh per TU Non peak
if(document.frmOne.coupling.checked==true)
{
if (((60*LRTCcapacity())/a*LRTMLS())<7)
{

```



```

b = 2;
}
else
{
b=1;
}
}
else
{
b=1;
}
return b;
}

function LRTNonPeakH()
{
var a=document.frmOne.LRTmlsratio2.value; //non peak factor
var npf = ((60*LRTNonPeakVeh()*LRTCcapacity()/(a*LRTMLS())); //non peak headway
npf = Math.floor(npf);
if(60%npf==0)
{
npf=npf;
}
else
{
while(60%npf!=0)
{npf = (npf-0.5);}
}
if(npf>30)
{
npf=30;
}
return npf;
}

function LRTNonPeakf()
{
var npf = (60/LRTNonPeakH());
if(npf<2)
{
npf=2;
} //non peak frequency
return npf;
}

function LRTTUnp()
{
var TUnp = Math.ceil(LRTCcycleTime()/LRTNonPeakH()); //off peak TU
return TUnp;
}

function LRTVehnp()
{
var Vehnp = LRTTUnp()*LRTNonPeakVeh(); //off peak vehs
return Vehnp;
}

```

```

}
function LRTNPTc()
{
NewTc = LRTTUnp()*LRTNonPeakH();
return NewTc;
}
function LRTNPTt()
{
Newtt = (LRTNPTc()-LRTOperatingTime())/2;
return Newtt;
}
function LRTLateNightVeh()
{
var a = document.frmOne.LRTmlratio3.value; //Late Night factor
var b; //Number of Veh per TU Late Night
if(document.frmOne.coupling.checked==true)
{
if (((60*LRTCcapacity())/(a*LRTMLS()))<7)
{
b = 2;
}
else
{
b=1;
}
}
else
{
b=1;
}
return b;
}
function LRTLateNightH()
{
var a=document.frmOne.LRTmlratio3.value; //late night factor
var lnh = ((60*LRTLateNightVeh()*LRTCcapacity())/(a*LRTMLS())); //Late Night headway
lnh = Math.floor(lnh);
if(60%lnh==0)
{
lnh=lnh;
}
else
{
while(60%lnh!=0)
{lnh = (lnh-0.5);}
}
if(lnh>30)
{lnh=30;}
return lnh;
}
function LRTLateNightf()

```

```

{
var lnf = (60/LRTLateNightH()); //Late night frequency
if(lnf<2)
{lnf=2;}
return lnf;
}

function LRTTUln()
{
var TUln = Math.ceil(LRTCycleTime()/LRTLateNightH()); //late night TU
return TUln;
}

function LRTVehln()
{
var Vehln = LRTTUln()*LRTLateNightVeh(); //late night vehs
return Vehln;
}

function LRTLNTc()
{
NewTc = LRTTUln()*LRTLateNightH();
return NewTc;
}

function LRTLNtt()
{
Newtt = (LRTLNTc()-LRTOperatingTime())/2;
return Newtt;
}

function LRTWeekendDayVeh()
{
var a = document.frmOne.LRTmlsratio4.value; //Weekend Day factor
var b; //Number of Veh per TU Weekend Day
if(document.frmOne.coupling.checked==true)
{
if (((60*LRTCcapacity())/(a*LRTMLS()))<7)
{
b = 2;
}
else
{
b=1;
}
}
else
{
b=1;
}
return b;
}

function LRTWeekendDayH()
{
var a=document.frmOne.LRTmlsratio4.value; //weekend day factor

```

```

var wdh = ((60*LRTWeekendDayVeh()*LRTCcapacity())/(a*LRTMLS())); //weekend day headway
wdh = Math.floor(wdh);
if(60%wdh==0)
{
wdh=wdh;
}
else
{
while(60%wdh!=0)
{wdh = (wdh-0.5);}
}
if(wdh>30)
{wdh=30;}
return wdh;
}

function LRTWeekendDayf()
{
var lmf = (60/LRTWeekendDayH()); //weekend day frequency
if(lmf<2)
{lmf=2;}
return lmf;
}

function LRTTUwd()
{
var TUwd = Math.ceil(LRTCcycleTime()/LRTWeekendDayH()); //weekend day TU
return TUwd;
}

function LRTVehwd()
{
var Vehwd = LRTTUwd()*LRTWeekendDayVeh(); //weekend day vehs
return Vehwd;
}

function LRTWDTc()
{
NewTc = LRTTUwd()*LRTWeekendDayH();
return NewTc;
}

function LRTWDtt()
{
Newtt = (LRTWDTc()-LRTOperatingTime())/2;
return Newtt;
}

function LRTWeekendNightVeh()
{
var a = document.frmOne.LRTmlsratio5.value; //Weekend Night factor
var b; //Number of Veh per TU Weekend Night
if(document.frmOne.coupling.checked==true)
{
if (((60*LRTCcapacity())/(a*LRTMLS()))<7)
{

```

```

b = 2;
}
else
{
b=1;
}
}
else
{
b=1;
}
return b;
}

function LRTWeekendNightH()
{
var a=document.frmOne.LRTmlsratio5.value; //weekend night factor
var wnh = ((60*LRTWeekendNightVeh()*LRTCcapacity()/(a*LRTMLS())); //weekend night headway
wnh = Math.floor(wnh);
if(60%wnh==0)
{
wnh=wnh;
}
else
{
while(60%wnh!=0)
{wnh = (wnh-0.5);}
}
if(wnh>30)
{wnh=30;}
return wnh;
}

function LRTWeekendNightf()
{
var wnf = (60/LRTWeekendNightH()); //weekend night frequency
if(wnf<2)
{wnf=2;}
return wnf;
}

function LRTTUwn()
{
var TUwn = Math.ceil(LRTCcycleTime()/LRTWeekendNightH()); //weekend night TU
return TUwn;
}

function LRTVehwn()
{
var Vehwn = LRTTUwn()*LRTWeekendNightVeh(); //weekend night vehs
return Vehwn;
}

function LRTWNTc()
{
NewTc = LRTTUwn()*LRTWeekendNightH();

```

```

return NewTc;
}
function LRTWNtt()
{
Newtt = (LRTWNTc()-LRTOperatingTime())/2;
return Newtt;
}

function LRTPeakOperatorHours()
{
var a=document.frmOne.LRThrsperdp1.value;
var b=a*LRTN();//Fleet required for peak hours
return b;
}

function LRTDayHours() //Midday and Early Evening Operator Hours
{
var a;
a=document.frmOne.LRThrsperdp2.value;
var b=a*LRTTUnp();
return b;
}

function LRTLHours()
{
var a=document.frmOne.LRThrsperdp3.value;
var b=a*LRTTUn();
return b;
}

function LRTDailyOpHours()
{
var a;
a=LRTPeakOperatorHours()+LRTDayHours()+LRTLHours();
return a;
}

function LRTWeekendDayHours()
{
var a;
a=document.frmOne.LRThrsperdp4.value;
var b;
b=a*LRTTUwd();
return b;
}

function LRTWeekendMornEveOpHours()
{
var a;
a=document.frmOne.LRThrsperdp5.value;
var b = a*LRTTUwn();
return b;
}

function LRTWeekendHours()
{
var a = LRTWeekendDayHours()+LRTWeekendMornEveOpHours();

```

```

return a;
}
function LRTAnnualOpHrs()
{
var a;
a=(LRTDailyOpHours()*252)+(LRTWeekendHours()*113);
return a;
}
function LRTPeakVehKm()
{
var b=document.frmOne.LRTl.value;
var c=LRTHeadway();
c=60/c;
var d=document.frmOne.LRThrsperdp1.value;
var a;
a=LRTvehTU()*c*2*b*d*252; //252 weekdays in one year
return a;
}
function LRTOffPeakVehKm()
{
var b=document.frmOne.LRTl.value;
var c=LRTNonPeakH();
c=60/c;
var d=document.frmOne.LRThrsperdp2.value;
var a;
a=LRTNonPeakVeh()*c*2*b*d*252;
return a;
}
function LRTLEVehKm()
{
var b=document.frmOne.LRTl.value;
var c=LRTLateNightH();
c=60/c;
var d=document.frmOne.LRThrsperdp3.value;
var a;
a=LRTLateNightVeh()*c*2*b*d*252;
return a;
}
function LRTSaturdayOffPeakVehKm()
{
var b=document.frmOne.LRTl.value;
var c=LRTWeekendDayH();
c=60/c;
var d=document.frmOne.LRThrsperdp4.value;
var a;
a=LRTWeekendDayVeh()*c*2*b*d*52;
return a;
}
function LRTSaturdayLEVehKm()
{

```

```

var b=document.frmOne.LRTl.value;
var c=LRTWeekendNightH();
c=60/c;
var d=document.frmOne.LRThrsperdp5.value;
var a;
a=LRTWeekendNightVeh()*c*2*b*d*52;
return a;
}

function LRTSundayOffPeakVehKm()
{
var b=document.frmOne.LRTl.value;
var c=LRTWeekendDayH();
c=60/c;
var d=document.frmOne.LRThrsperdp4.value;
var a;
a=LRTWeekendDayVeh()*c*2*b*d*61;
return a;
}

function LRTSundayLEVehKm()
{
var b=document.frmOne.LRTl.value;
var c=LRTWeekendNightH();
c=60/c;
var d=document.frmOne.LRThrsperdp5.value;
var a;
a=LRTWeekendNightVeh()*c*2*b*d*61;
return a;
}

function LRTVehKm()
{
var
a=LRTPeakVehKm()+LRTOffPeakVehKm()+LRTLEVehKm()+LRTSaturdayOffPeakVehKm()+LRTSaturdayLEVehKm()+LRTSu
ndayOffPeakVehKm()+LRTSundayLEVehKm();
return a;
}

function LRTMaxVehService()
{
var a=Math.max(LRTVehPeak(),LRTVehnp(),LRTVehln());
return a;
}

function CommaFormatted(amount) //This function was developed by William Bontrager's article in Web-Source.net
{
var delimiter=",";
var a = amount.split('.',2)
var d = a[1];
var i = parseInt(a[0]);
if(isNaN(i))
{
return "";
}
var minus = "";

```



```

if(i<0)
{
minus = '-';
}
i = Math.abs(i);
var n = new String(i);
var a = [];
while(n.length>3)
{
var nn = n.substr(n.length-3);
a.unshift(nn);
n = n.substr(0,n.length-3);
}
if(n.length>0)
{
a.unshift(n);
}
n = a.join(delimiter);
if(d.length<1)
{
amount=n;
}
else
{
amount = n + '.' + d;
}
amount = minus + amount;
return amount;
}

function LRTOC()
{
var a = document.frmOne.LRToc.value;
var g = document.frmOne.LRTocgr.value;
var c = document.frmOne.LRTp.value;
var i = document.frmOne.LRTi.value;
var d = a*LRTAnnualOpHrs();
var e = d*((1-Math.pow((1+g/100),c)*Math.pow((1+i/100),(-c)))/(i/100-g/100));
var f = e*(i/100*Math.pow((1+i/100),c))/(Math.pow((1+i/100),c)-1);
return f;
}

function LRTEC()
{
var a = document.frmOne.LRTE.value;
a=Number(a);
var b = document.frmOne.LRTE2.value;
var g = document.frmOne.LRTEgr.value;
var c = document.frmOne.LRTp.value;
var i = document.frmOne.LRTi.value;
var d = a*b*LRTVehKm();
var e = d*((1-Math.pow((1+g/100),c)*Math.pow((1+i/100),(-c)))/(i/100-g/100));
var f = e*(i/100*Math.pow((1+i/100),c))/(Math.pow((1+i/100),c)-1);

```

```

return f;
}
function LRTEnergyConsumption()
{
var ecperveh=document.frmOne.LRTE.value;
var vehkm=LRTVehKm();
var tec= ecperveh*vehkm; //total annual energy consumption
document.frmOne.LRTEneConsump.value=tec;
return tec;
}
function LRTVC()
{
var vc = document.frmOne.LRTvc.value;
vc=Number(vc);
var b = document.frmOne.LRTsl.value;
b=Number(b);
var c = document.frmOne.LRTP.value;
c=Number(c);
var i = document.frmOne.LRTi.value;
i=Number(i);
var d = (vc*(i/100)/(1-1/Math.pow((1+i/100),b)));
var e = d*(c/b)*LRTMaxVehService();
return e;
}
function LRTMC()
{
var a = document.frmOne.LRTvmc.value;
var b = document.frmOne.LRTimc.value;
var g = document.frmOne.LRTmcgr.value;
var c = document.frmOne.LRTP.value;
var i = document.frmOne.LRTi.value;
var l = document.frmOne.LRTL.value;
var d = a*LRTVehKm()+b*l;
var e = d*((1-Math.pow((1+g/100),c)*Math.pow((1+i/100),(-c)))/(i/100-g/100));
var f = e*(i/100*Math.pow((1+i/100),c))/(Math.pow((1+i/100),c)-1);
return f;
}
function LRTSC()
{
var a = document.frmOne.LRTsc.value;
b=Number(b);
var b = document.frmOne.LRTsta.value;
c=Number(c);
var c = document.frmOne.LRTP.value;
b=Number(b);
var i = document.frmOne.LRTi.value;
i=Number(i);
var d = (a)*(i/100)/(1-1/Math.pow((1+i/100),c));
var e = d*b;
return e;
}
}

```

```

function LRTICCO()
{
var ic = document.frmOne.LRTinf.value;
ic=Number(ic);
var b = document.frmOne.LRTp.value;
b=Number(b);
var i = document.frmOne.LRTi.value;
i=Number(i);
var l = document.frmOne.LRTL.value;
l=Number(l);
var d = (ic)*(i/100)/(1-1/Math.pow((1+i/100),b));
var e = d*l;
return e;
}

function ValuestoCurrency()
{
var a=LRTOC();
a=a.toFixed(2);
a=CommaFormatted(a);
document.frmOne.LRTOperatingCost.value = a;
var b=LRTEC();
b=b.toFixed(2);
b=CommaFormatted(b);
document.frmOne.LRTEnergyCost.value = b;
var c=LRTVC();
c=c.toFixed(2);
c=CommaFormatted(c);
document.frmOne.LRTVehicleCost.value = c;
var d=LRTMC();
d=d.toFixed(2);
d=CommaFormatted(d);
document.frmOne.LRTMaintenanceCost.value = d;
var e=LRTSC();
e=e.toFixed(2);
e=CommaFormatted(e);
document.frmOne.LRTStaConstructionCost.value = e;
var f=LRTICCO();
f=f.toFixed(2);
f=CommaFormatted(f);
document.frmOne.LRTInfCost.value = f;
}

function TotalAnnualLRTCOST()
{
ValuestoCurrency();
var a=LRTOC()+LRTEC()+LRTVC()+LRTMC()+LRTSC()+LRTICCO();
a=Number(a);
a=a.toFixed(2);
a=CommaFormatted(a);
document.frmOne.LRTTotalAnnualCost.value = a;
return a;
}

```

```

function BRTCcapacity()
{
a = document.frmOne.BRTcv.value;
b = document.frmOne.BRTAlpha.value;
a = Number(a);
b = Number(b);
c = (a * b);
return c;
}

function BRTMLS()
{
var a = document.frmOne.BRTMLS.value;
a=Number(a);
return a;
}

function BRTvehTU()
{
var veh=1;
return veh;
}

function BRTTUCap()
{
var tucap;
tucap = BRTCcapacity()*BRTvehTU();
return tucap;
}

function BRTFrequency()
{
var f;
f = (BRTMLS()/BRTTUCap());
if(f<2)
{
f=2;
}
return f;
}

function BRTHeadway()
{
var h;
h = Math.floor(60/BRTFrequency());
if(60%h==0)
{
h=h;
}
else
{
while(60%h!=0)
{h = (h-0.5);}
}
return h
}

```

```

function BRTOperatingTime()
{
a = document.frmOne.BRTvo.value;
b = document.frmOne.BRTl.value;
a = Number(a); //Vo
b = Number(b); //L
c = (120*(b/a)); //To
return c;
}

function BRTCycleTime()
{
d = document.frmOne.BRTtt.value;
d = Number(d); //tt
rt= (BRTOperatingTime() + (2*d)); //T
return rt;
}

function BRTN()
{
var N =(BRTCycleTime()/BRTHeadway()); //N peak hour
N = Math.ceil(N);
return N;
}

function BRTVehPeak()
{
vehs = Math.round(BRTN()*BRTvehTU()); //vehicles needed in peak hour
return vehs;
}

function BRTPeakTc()
{
newtc=(BRTN()*BRTHeadway()); //New Cycle Timepeak hour
return newtc;
}

function BRTPeaktt()
{
optt =((BRTPeakTc()-BRTOperatingTime())/2); //New terminal time peak hour
return optt;
}

function BRTTotalVehPeak()
{
a = document.frmOne.BRTsr.value;
a = Number(a);
a = a/100;
vehs = ((1+a)*BRTVehPeak()) //Total Vehicles Required for Both Peaks
vehs = Math.ceil(vehs);
return vehs;
}

function BRTNonPeakVeh()
{
var b=1;
return b;
}

```

```

}
function BRTNonPeakH()
{
var a=document.frmOne.BRTmlratio2.value; //non peak factor
var npf = ((60*BRTNonPeakVeh()*BRTCcapacity()/(a*BRTMLS())); //non peak headway
nph = Math.floor(npf);
if(60%nph==0)
{
nph=nph;
}
else
{
while(60%nph!=0)
{npf = (npf-0.5);}
}
if(npf>30)
{
nph=30;
}
return npf;
}
function BRTNonPeakf()
{
var npf = (60/BRTNonPeakH()); //non peak frequency
if(npf<2)
{
npf=2;
}
return npf;
}
function BRTTUnp()
{
var TUnp = Math.ceil(BRTCcycleTime()/BRTNonPeakH()); //off peak TU
return TUnp;
}
function BRTVehnp()
{
var Vehnp = BRTTUnp()*BRTNonPeakVeh(); //off peak vehs
return Vehnp;
}
function BRTNPTc()
{
NewTc = BRTTUnp()*BRTNonPeakH();
return NewTc;
}
function BRTNPtt()
{
Newtt = (BRTNPTc()-BRTOperatingTime())/2;
return Newtt;
}

```

```

function BRTLateNightVeh()
{
var b=1;
return b;
}

function BRTLateNightH()
{
var a=document.frmOne.BRTmlratio3.value; //late night factor
var lnh = ((60*BRTLateNightVeh()*BRTCcapacity()/(a*BRTMLS())); //Late Night headway
lnh = Math.floor(lnh);
if(60%lnh==0)
{
lnh=lnh;
}
else
{
while(60%lnh!=0)
{lnh = (lnh-0.5);}
}
if(lnh>30)
{
lnh=30;
}
return lnh;
}

function BRTLateNightf()
{
var lnf = (60/BRTLateNightH()); //Late night frequency
if(lnf<2)
{
lnf=2;
}
return lnf;
}

function BRTTUln()
{
var TUln = Math.ceil(BRTCcycleTime()/BRTLateNightH()); //late night TU
return TUln;
}

function BRTVehln()
{
var Vehln = BRTTUln()*BRTLateNightVeh(); //late night vehs
return Vehln;
}

function BRTLNTc()
{
NewTc = BRTTUln()*BRTLateNightH();
return NewTc;
}

function BRTLNtt()

```

```

{
Newtt = (BRTLNTc()-BRTOperatingTime())/2;
return Newtt;
}

function BRTWeekendDayVeh()
{
var b=1;
return b;
}

function BRTWeekendDayH()
{
var a=document.frmOne.BRTmlratio4.value; //weekend day factor
var wdh = ((60*BRTWeekendDayVeh()*BRTCcapacity())/(a*BRTMLS())); //weekend day headway
wdh = Math.floor(wdh);
if(60%wdh==0)
{
wdh=wdh;
}
else
{
while(60%wdh!=0)
{wdh = (wdh-0.5);}
}
if(wdh>30)
{
wdh=30;
}
return wdh;
}

function BRTWeekendDayf()
{
var wdf = (60/BRTWeekendDayH()); //weekend day frequency
if(wdf<2)
{
wdf=2;
}
return wdf;
}

function BRTTUwd()
{
var TUwd = Math.ceil(BRTCcycleTime()/BRTWeekendDayH()); //weekend day TU
return TUwd;
}

function BRTVehwd()
{
var Vehwd = BRTTUwd()*BRTWeekendDayVeh(); //weekend day vehs
return Vehwd;
}

function BRTWDTc()
{

```



```

NewTc = BRTTUwd()*BRTWeekendDayH());
return NewTc;
}
function BRTWDtt()
{
Newtt = (BRTWDTc()-BRTOperatingTime())/2;
return Newtt;
}
function BRTWeekendNightVeh()
{
var b; //Number of Veh per TU Weekend Night
b=1;
return b;
}
function BRTWeekendNightH()
{
var a=document.frmOne.BRTmlsratio5.value; //weekend night factor
var wnh = ((60*BRTWeekendNightVeh()*BRTCcapacity())/(a*BRTMLS())); //weekend night headway
wnh = Math.floor(wnh);
if(60%wnh==0)
{
wnh=wnh;
}
else
{
while(60%wnh!=0)
{wnh = (wnh-0.5);}
}
if(wnh>30)
{
wnh=30;
}
return wnh;
}
function BRTWeekendNightf()
{
var wnf = (60/BRTWeekendNightH()); //weekend night frequency
if(wnf<2)
{
wnf=2;
}
return wnf;
}
function BRTTUwn()
{
var TUwn = Math.ceil(BRTCcycleTime()/BRTWeekendNightH()); //weekend night TU
return TUwn;
}
function BRTVehwn()
{

```

```

var Vehwn = BRTTUwn()*BRTWeekendNightVeh(); //weekend night vehs
return Vehwn;
}
function BRTWNTc()
{
NewTc = BRTTUwn()*BRTWeekendNightH();
return NewTc;
}
function BRTWNtt()
{
Newtt = (BRTWNTc()-BRTOperatingTime())/2;
return Newtt;
}
function BRTPeakOperatorHours()
{
var a=document.frmOne.BRThrsperdp1.value;
a=(a*BRTN());
return a;
}
function BRTDayHours() //Midday and Early Evening Operator Hours
{
var a;
a=document.frmOne.BRThrsperdp2.value;
var b=a*BRTTUnp();
return b;
}
function BRTLHours()
{
var a=document.frmOne.BRThrsperdp3.value;
a=a*BRTUln();
return a;
}
function BRTWeeklyOpHours()
{
var a;
a=BRTPeakOperatorHours()+BRTDayHours()+BRTLHours();
return a;
}
function BRTWeekendDayHours()
{
var a;
a=document.frmOne.BRThrsperdp4.value;
var b;
b=a*BRTTUwd();
return b;
}
function BRTWeekendMornEveOpHours()
{
var a;
a=document.frmOne.BRThrsperdp5.value;

```

```

var b = a*BRTTUwn();
return b;
}

function BRTWeekendHours()
{
var a = BRTWeekendDayHours()+BRTWeekendMornEveOpHours();
return a;
}

function BRTAnnualOpHrs()
{
var a;
a=(BRTWeeklyOpHours()*252)+(BRTWeekendHours()*113);
return a;
}

function BRTPeakVehKm()
{
var b=document.frmOne.BRTl.value;
var c=BRTHeadway();
c=60/c;
var d=document.frmOne.BRThrsperdp1.value;
var a;
a=BRTvehTU()*c*2*b*d*252;
return a;
}

function BRTOffPeakVehKm()
{
var b=document.frmOne.BRTl.value;
var c=BRTNonPeakH();
c=60/c;
var d=document.frmOne.BRThrsperdp2.value;
var a;
a=BRTNonPeakVeh()*c*2*b*d*252;
return a;
}

function BRTLVEhKm()
{
var b=document.frmOne.BRTl.value;
var c=BRTLateNightH();
c=60/c;
var d=document.frmOne.BRThrsperdp3.value;
var a;
a=BRTLateNightVeh()*c*2*b*d*252;
return a;
}

function BRTWeekendOffPeakVehKm()
{
var b=document.frmOne.BRTl.value;
var c=BRTWeekendDayH();
c=60/c;
var d=document.frmOne.BRThrsperdp4.value;

```

```

var a;
a=BRTWeekendDayVeh()*c*2*b*d*113;
return a;
}

function BRTWeekendLEVehKm()
{
var b=document.frmOne.BRTl.value;
var c=BRTWeekendNightH();
c=60/c;
var d=document.frmOne.BRThrsperdp5.value;
var a;
a=BRTWeekendNightVeh()*c*2*b*d*113;
return a;
}

function BRTVehKm()
{
var a=BRTPeakVehKm()+BRTOffPeakVehKm()+BRTLEVehKm()+BRTWeekendOffPeakVehKm()+BRTWeekendLEVehKm();
return a;
}

function BRTMaxVehService()
{
var a=Math.max(BRTVehPeak(),BRTVehnp(),BRTVehln());
return a;
}

function CommaFormatted(amount)
{
var delimiter=",";
var a = amount.split('.',2)
var d = a[1];
var i = parseInt(a[0]);
if(isNaN(i))
{
return "";
}
var minus = "";
if(i<0)
{
minus = '-';
}
i = Math.abs(i);
var n = new String(i);
var a = [];
while(n.length>3)
{
var nn = n.substr(n.length-3);
a.unshift(nn);
n = n.substr(0,n.length-3);
}
if(n.length>0)
{
a.unshift(n);
}
}

```

```

}
n = a.join(delimiter);
if(d.length<1)
{
amount=n;
}
else
{
amount = n + '.' + d;
}
amount = minus + amount;
return amount;
}

function BRTOC()
{
var a = document.frmOne.BRToc.value;
var g = document.frmOne.BRTocgr.value;
var c = document.frmOne.BRTp.value;
var i = document.frmOne.BRTi.value;
var d = a*BRTAnnualOpHrs();
var e = d*((1-Math.pow((1+g/100),c)*Math.pow((1+i/100),(-c)))/(i/100-g/100));
var f = e*(i/100*Math.pow((1+i/100),c))/(Math.pow((1+i/100),c)-1);
return f;
}

function BRTEC()
{
var a = document.frmOne.BRTE.value;
var b = document.frmOne.BRTE2.value;
var g = document.frmOne.BRTegr.value;
var c = document.frmOne.BRTp.value;
var i = document.frmOne.BRTi.value;
var d = a*b*BRTVehKm();
var e = d*((1-Math.pow((1+g/100),c)*Math.pow((1+i/100),(-c)))/(i/100-g/100));
var f = e*(i/100*Math.pow((1+i/100),c))/(Math.pow((1+i/100),c)-1);
return f;
}

function BRTEnergyConsumption()
{
var ecperveh=document.frmOne.BRTE.value;
var vehkm=BRTVehKm();
var tec= ecperveh*vehkm; //total annual energy consumption
document.frmOne.BRTeneConsump.value=tec;
return tec;
}

function BRTVC()
{
var vc = document.frmOne.BRTvc.value;
vc=Number(vc);
var b = document.frmOne.BRTsl.value;
b=Number(b);
var c = document.frmOne.BRTp.value;

```

```

c=Number(c);
var i = document.frmOne.BRTi.value;
i=Number(i);
var d = (vc)*(i/100)/(1-1/Math.pow((1+i/100),b));
var e = d*(c/b)*BRTMaxVehService();
return e;
}

function BRTMC()
{
var a = document.frmOne.BRTvmc.value;
var b = document.frmOne.BRTimc.value;
var g = document.frmOne.BRTmcgr.value;
var c = document.frmOne.BRTp.value;
var i = document.frmOne.BRTi.value;
var l = document.frmOne.BRTL.value;
var d = a*BRTVehKm()+l*b;
var e = d*((1-Math.pow((1+g/100),c)*Math.pow((1+i/100),(-c)))/(i/100-g/100));
var f = e*(i/100*Math.pow((1+i/100),c))/(Math.pow((1+i/100),c)-1);
return f;
}

function BRTSC()
{
var a = document.frmOne.BRTsc.value;
b=Number(b);
var b = document.frmOne.BRTsta.value;
c=Number(c);
var c = document.frmOne.BRTp.value;
b=Number(b);
var i = document.frmOne.BRTi.value;
i=Number(i);
var d = (a)*(i/100)/(1-1/Math.pow((1+i/100),c));
var e = d*b;
return e;
}

function BRTICC()
{
var ic = document.frmOne.BRTinf.value;
ic=Number(ic);
var b = document.frmOne.BRTp.value;
b=Number(b);
var i = document.frmOne.BRTi.value;
i=Number(i);
var l = document.frmOne.BRTL.value;
l=Number(l);
var d = (ic)*(i/100)/(1-1/Math.pow((1+i/100),b));
var e = d*l;
return e;
}

function ValuestoCurrencyB()
{
var a=BRTOC();

```

```

a=a.toFixed(2);
a=CommaFormatted(a);
document.frmOne.BRTOperatingCost.value = a;
var b=BRTEC();
b=b.toFixed(2);
b=CommaFormatted(b);
document.frmOne.BRTEnergyCost.value = b;
var c=BRTVC();
c=c.toFixed(2);
c=CommaFormatted(c);
document.frmOne.BRTVehicleCost.value = c;
var d=BRTMC();
d=d.toFixed(2);
d=CommaFormatted(d);
document.frmOne.BRTMaintenanceCost.value = d;
var e=BRTSC();
e=e.toFixed(2);
e=CommaFormatted(e);
document.frmOne.BRTStaConstructionCost.value = e;
var f=BRTICC();
f=f.toFixed(2);
f=CommaFormatted(f);
document.frmOne.BRTInfCost.value = f;
}

function TotalAnnualBRTCost()
{
ValuetoCurrencyB();
var a=BRTOC()+BRTEC()+BRTVC()+BRTMC()+BRTSC()+BRTICC();
a=Number(a);
a=a.toFixed(2);
a=CommaFormatted(a);
document.frmOne.BRTTotalAnnualCost.value = a;
return a;
}
</script>
<script>
function RadarGraph()
{
var lr = document.frmOne.LRT1.value;
var lb = document.frmOne.BRT1.value;
var radar = new RGraph.Radar('radar1',[LRTOC(),LRTEC(),LRTVC(),LRTMC(),(LRTICC()/lr)],
[BRTOC(),BRTEC(),BRTVC(),BRTMC(),(BRTICC()/lb)]);
radar.Set('chart.strokestyle','black');
radar.Set('chart.colors.alpha',0.5);
radar.Set('chart.colors', ['red','blue']);
if(!RGraph.isOld()){
radar.Set('chart.tooltips.effect','snap');
radar.Set('chart.tooltips', [
'LC','EC','VC','MC','ICC',
'LC','EC','VC','MC','ICC',
]);
}
}

```

```

}
radar.Set('chart.labels',['Labor Cost','Energy Cost','Vehicle Capital Cost','Maintenance Cost','Infrastructure Cost/km']);
radar.Set('chart.gutter.top', 35);
//radar.Set('chart.accumulative',true);
radar.Set('chart.key', ['LRT','BRT']);
radar.Set('chart.text.size', 10);
radar.Set('chart.key.interactive',true);
radar.Set('chart.key.rounded', false);
radar.Set('chart.key.shadow',true);
radar.Set('chart.key.shadow.offsetx', 3);
radar.Set('chart.key.shadow.offsety', 3);
radar.Set('chart.key.shadow.blur', 0);
radar.Set('chart.key.shadow.color', '#aaa');
radar.Draw();
}
function BarGraph()
{
var bar3 = new RGraph.Bar('bar1', [LRTFrequency(), LRTNonPeakf(), LRTLateNightf()]);
bar3.Set('chart.labels', ['Peak f', 'Off Peak f', 'Late Evening f']);
bar3.Set('chart.tooltips', ['Peak', 'Off Peak', 'Late Evening']);
bar3.Set('chart.colors', ['red']);
bar3.Set('chart.shadow', true);
bar3.Set('chart.shadow.offsetx', 3);
bar3.Set('chart.shadow.offsety', -3);
bar3.Set('chart.shadow.blur', 5);
bar3.Set('chart.shadow.color', '#ccc');
bar3.Set('chart.background.grid', false);
bar3.Draw();

var bar3 = new RGraph.Bar('bar2', [BRTFrequency(), BRTNonPeakf(), BRTLateNightf()]);
bar3.Set('chart.labels', ['Peak f', 'Off Peak f', 'Late Evening f']);
bar3.Set('chart.tooltips', ['Peak', 'Off Peak', 'Late Evening']);
bar3.Set('chart.colors', ['blue']);
bar3.Set('chart.shadow', true);
bar3.Set('chart.shadow.offsetx', 3);
bar3.Set('chart.shadow.offsety', -3);
bar3.Set('chart.shadow.blur', 5);
bar3.Set('chart.shadow.color', '#ccc');
bar3.Set('chart.background.grid', false);
bar3.Draw();
}

//Break-Even Point Calculation
function LRTAnnualCost(MLS)
{
a = document.frmOne.LRTcv.value;
b = document.frmOne.Alpha.value;
a = Number(a);
b = Number(b);
c = (a * b);//capacity;
var veh;
if(document.frmOne.coupling.checked==true)//veh per TU

```



```

{
if(MLS/c>12)
{
veh=2;
}
else
{
veh=1;
}
}
else veh=1;
var tucap;//TU capacity
tucap = c*veh;
var f;//frequency
f = (MLS/tucap);
var h;//headway
h = Math.floor(60/f);
if(60%h==0)
{
h=h;
}
else
{
while(60%h!=0)
{h = (h-0.5);}
}
var vo = document.frmOne.LRTvo.value;
var l = document.frmOne.LRTl.value;
vo = Number(vo); //Vo
l = Number(l); //L
var g = (120*(l/vo)); //To
var k = document.frmOne.LRTt.value;
k = Number(k); //tt
var rt= (g + (2*k)); //T
var N =(rt/h); //N peak hour
N = Math.ceil(N);
var vehs = Math.round(N*veh); //vehicles needed in peak hour
var newtc=(N*h); //New (Operational) Cycle Timepeak hour
var optt =((newtc-g)/2); //New terminal time peak hour
var m = document.frmOne.LRTsr.value;
m = Number(m);
m = m/100;
vehstotal = ((1+m)*vehs) //Total Vehicles Required for Both Peaks
vehstotal = Math.ceil(vehstotal);
var o = document.frmOne.LRTmlsratio2.value; //Non peak factor
var p; //Number of Veh per TU Non peak
if(document.frmOne.coupling.checked==true)
{
if (((60*c)/(o*MLS))<7)

```

```

{
p = 2;
}
else
{
p=1;
}
}
else
{
p=1;
}
}

var nph = ((60*p*c)/(o*MLS)); //non peak headway
nph = Math.floor(nph);
if(60%nph==0)
{
nph=nph;
}
else
{
while(60%nph!=0)
{nph = (nph-0.5);}
}

var npf = (60/nph); //non peak frequency
var TUnp = Math.ceil(rt/nph); //off peak TU
var Vehnp = TUnp*p; //off peak vehs
var NewTcnp = TUnp*nph;
var Newtt = (NewTcnp-g)/2;
var q = document.frmOne.LRTmlsratio3.value; //Late Night factor
var r; //Number of Veh per TU Late Night
if(document.frmOne.coupling.checked==true)
{
if (((60*c)/(q*MLS))<7)
{
r = 2;
}
}
else
{
r=1;
}
}
else
{
r=1;
}
}

var lnh = ((60*r*c)/(q*MLS)); //Late Night headway
lnh = Math.floor(lnh);
if(60%lnh==0)
{
lnh=lnh;
}
}

```

```

}
else
{
while(60%lnh!=0)
{lnh = (lnh-0.5);}
}
var lnf = (60/lnh); //Late night frequency
var TULn = Math.ceil(rt/lnh); //late night TU
var Vehln = TULn*r; //late night vehs
var lnNewTc = TULn*lnh;
lnNewtt = (lnNewTc-g)/2;
var u=document.frmOne.LRThrsperdp1.value;
u=u*vehs;//Fleet required for peak hours
var wdhrs=document.frmOne.LRThrsperdp2.value;
var npwdhrs=wdhrs*TULn;
var lnhrs=document.frmOne.LRThrsperdp3.value;
lnhrs=lnhrs*TULn;
var weekophrs;
weekophrs=u+npwdhrs+lnhrs;
var w = document.frmOne.LRTmlratio4.value; //Non peak factor
var ww; //Number of Veh per TU Non peak
if(document.frmOne.coupling.checked==true)
{
if (((60*c)/(v*MLS))<7)
{
ww = 2;
}
else
{
ww=1;
}
}
else
{
ww=1;
}
}
var wnpn = ((60*ww*c)/(w*MLS)); //non peak headway
wnpn = Math.floor(wnpn);
if(60%wnpn==0)
{
wnpn=wnpn;
}
else
{
while(60%wnpn!=0)
{wnpn = (wnpn-0.5);}
}
}
var wnpf = (60/wnpn); //non peak frequency

```

```

var TUwnp = Math.ceil(rt/wnph); //off peak TU
var Vehwnp = TUwnp*ww; //off peak vehs
var NewTcwnp = TUwnp*wnph;
var Newwtt = (NewTcwnp-g)/2;
var v=document.frmOne.LRTmlratio5.value;
var vv; //Number of Veh per TU Late Night
if(document.frmOne.coupling.checked==true)
{
if (((60*c)/(v*MLS))<7)
{
vv = 2;
}
else
{
vv=1;
}
}
else
{
vv=1;
}
}
var wlnh = ((60*vv*c)/(v*MLS)); //Late Night headway
wlnh = Math.floor(wlnh);
if(60%wlnh==0)
{
wlnh=wlnh;
}
else
{
while(60%wlnh!=0)
{wlnh = (wlnh-0.5);}
}
var wlnf = (60/wlnh); //Late night frequency
var TUwln = Math.ceil(rt/wlnh); //late night TU
var Vehwln = TUwln*v; //late night vehs
var wlnNewTc = TUwln*wlnh;
var wlnNewtt = (wlnNewTc-g)/2;
var www;
www=document.frmOne.LRThrsperdp4.value;
var npwehrs = www*TUwnp;
var vvv;
vvv=document.frmOne.LRThrsperdp5.value;
var lnwehrs = vvv*TUwln;
var totwehrs = npwehrs+lnwehrs;
var ophrs;
ophrs=(weekophrs*252)+(totwehrs/113);
f=60/h;
var pvehkm;

```

```

var pkhrs=document.frmOne.LRThrsperdp1.value;
pvehkm=veh*f*2*1*pkhrs*252;

npf=60/nph;
var wdhrs=document.frmOne.LRThrsperdp2.value;
var npvehkm;
npvehkm=p*npf*2*1*wdhrs*252;

lnf=60/lnh;
var lnhrs=document.frmOne.LRThrsperdp3.value;
var levehkm;
levehkm=r*lnf*2*1*lnhrs*252;

var cc=wnph;
cc=60/cc;

var dd=document.frmOne.LRThrsperdp4.value;
var satopvehkm;
satopvehkm=w*cc*2*1*dd*52;

var ccc=wlh;
var ccc=60/ccc;
var ddd=document.frmOne.LRThrsperdp5.value;
var satlevehkm;
satlevehkm=v*ccc*2*1*ddd*52;

var sundnpvehkm;
sundnpvehkm=w*cc*2*1*dd*61;

var sundlevehkm;
sundlevehkm=v*ccc*2*1*ddd*61;

var totalvehkm=pvehkm+npvehkm+levehkm+satopvehkm+satlevehkm+sundnpvehkm+sundlevehkm;
var maxvehsrvc=Math.max(vehs,Vehnp,Vehln);

var oc = document.frmOne.LRToc.value;
var ocg = document.frmOne.LRTocgr.value;
var period = document.frmOne.LRTp.value;
var ir = document.frmOne.LRTi.value;
if(ocg==ir)
{ocg=ocg+0.0000001;}
var ocvalue = oc*ophrs;
var ocpresent = ocvalue*((1-Math.pow((1+ocg/100),period)*Math.pow((1+ir/100),(-period)))/(ir/100-ocg/100));
var ocanual = ocpresent*(ir/100*Math.pow((1+ir/100),period))/(Math.pow((1+ir/100),period)-1);

var ec = document.frmOne.LRTE.value;
ec=Number(ec);
var ec2 = document.frmOne.LRTE2.value;
var ecg = document.frmOne.LRTegr.value;
if(ecg==ir)
{ecg=ecg+0.0000001;}
var ecvalue = ec2*ec*totalvehkm;
var ecpresent = ecvalue*((1-Math.pow((1+ecg/100),period)*Math.pow((1+ir/100),(-period)))/(ir/100-ecg/100));
var ecanual = ecpresent*(ir/100*Math.pow((1+ir/100),period))/(Math.pow((1+ir/100),period)-1);

var vc = document.frmOne.LRTvc.value;
vc=Number(vc);
var sl = document.frmOne.LRTsl.value;
sl=Number(sl);
var vcvalue = (vc)*(ir/100)/(1-1/Math.pow((1+ir/100),sl));

```

```

var vannual = vcvalue*(period/sl)*maxvehsrv;
var vmc = document.frmOne.LRTvmc.value;
var imc = document.frmOne.LRTimc.value;
var mcg = document.frmOne.LRTmcgr.value;
if(mcg==ir)
{mcg=mcg+0.0000001;}
var mcvalue = vmc*totalvehkm+l*imc;
var mcpresent = mcvalue*((1-Math.pow((1+mcg/100),period)*Math.pow((1+ir/100),(-period)))/(ir/100-mcg/100));
var mcannual = mcpresent*(ir/100*Math.pow((1+ir/100),period))/(Math.pow((1+ir/100),period)-1);

var sc = document.frmOne.LRTsc.value;
sc=Number(sc);
var sta = document.frmOne.LRTsta.value;
sta=Number(sta);
var scc = sc*sta;

var ic = document.frmOne.LRTinf.value;
ic=Number(ic);
var icc = (ic)*(ir/100)/(1-1/Math.pow((1+ir/100),period));
var icckm = icc*;

var lrtcost=icckm+scc+mcannual+vannual+ecannual+ocannual;
return lrtcost;
}

function BRTAnnualCost(MLS)
{
a = document.frmOne.BRTcv.value;
b = document.frmOne.Alpha.value;
a = Number(a);
b = Number(b);
c = (a * b);//capacity;

var veh;
veh=1;

var tucap;//TU capacity
tucap = c*veh;

var f;//frequency
f = (MLS/tucap);

var h;//headway
h = Math.floor(60/f);
if(60%h==0)
{
h=h;
}
else
{
while(60%h!=0)
{h = (h-0.5);}
}

var vo = document.frmOne.BRTvo.value;
var l = document.frmOne.BRTL.value;
vo = Number(vo); //Vo
l = Number(l); //L

```

```

var g = (120*(l/vo)); //To
var k = document.frmOne.BRTtt.value;
k = Number(k); //tt
var rt= (g + (2*k)); //T
var N =(rt/h); //N peak hour
N = Math.ceil(N);
var vehs = Math.round(N*veh); //vehicles needed in peak hour
var newtc=(N*h); //New (Operational) Cycle Timepeak hour
var optt=((newtc-g)/2); //New terminal time peak hour
var m = document.frmOne.BRTsr.value;
m = Number(m);
m = m/100;
vehstotal = ((1+m)*vehs) //Total Vehicles Required for Both Peaks
vehstotal = Math.ceil(vehstotal);
var o = document.frmOne.BRTmlratio2.value; //Non peak headway factor
var p; //Number of Veh per TU Non peak
p=1;
var nph = ((60*p*c)/(o*MLS)); //non peak headway
nph = Math.floor(nph);
if(60%nph==0)
{
nph=nph;
}
else
{
while(60%nph!=0)
{nph = (nph-0.5);}
}
var npf = (60/nph); //non peak frequency
var TUnp = Math.ceil(rt/nph); //off peak TU
var Vehnp = TUnp*p; //off peak vehs
var NewTcnp = TUnp*nph;
var Newtt = (NewTcnp-g)/2;
var q = document.frmOne.BRTmlratio3.value; //Late Night factor
var r; //Number of Veh per TU Late Night
r=1;
var lnh = ((60*r*c)/(q*MLS)); //Late Night headway
lnh = Math.floor(lnh);
if(60%lnh==0)
{
lnh=lnh;
}
else
{
while(60%lnh!=0)
{lnh = (lnh-0.5);}
}
var lnf = (60/lnh); //Late night frequency

```

```

var TUln = Math.ceil(rt/lnh); //late night TU
var Vehln = TUln*r; //late night vehs
var lnNewTc = TUln*lnh;
var lnNewtt = (lnNewTc-g)/2;

var u=document.frmOne.BRThrsperdp1.value;
u=u*vehs;//Fleet required for peak hours (times 2 because there are 2 peak times)
var wdhrs=document.frmOne.BRThrsperdp2.value;
var npwdhrs=wdhrs*TUln;
var lnhrs=document.frmOne.BRThrsperdp3.value;
lnhrs=lnhrs*TUln;
var weekophrs;
weekophrs=u+npwdhrs+lnhrs;
var w = document.frmOne.BRTmlratio4.value; //Non peak factor
var ww; //Number of Veh per TU Non peak
if(document.frmOne.coupling.checked==true)
{
if (((60*c)/(w*MLS))<7)
{
ww = 2;
}
else
{
ww=1;
}
}
else
{
ww=1;
}
}

var wnph = ((60*ww*c)/(w*MLS)); //non peak headway
wnph = Math.floor(wnph);
if(60%wnph==0)
{
wnph=wnph;
}
else
{
while(60%wnph!=0)
{wnph = (wnph-0.5);}
}

var wnpf = (60/wnph); //non peak frequency
var TUwnp = Math.ceil(rt/wnph); //off peak TU
var Vehwnp = TUwnp*w; //off peak vehs
var NewTcwnp = TUwnp*wnph;
var Newtt = (NewTcwnp-g)/2;

var v=document.frmOne.BRTmlratio5.value;
var vv; //Number of Veh per TU Late Night
vv=1;

```



```

var wlnh = ((60*vv*c)/(v*MLS)); //Late Night headway
wlnh = Math.floor(wlnh);
if(60%wlnh==0)
{
wlnh=wlnh;
}
else
{
while(60%wlnh!=0)
{wlnh = (wlnh-0.5);}
}

var wlnf = (60/wlnh); //Late night frequency
var TUwln = Math.ceil(rt/wlnh); //late night TU
var Vehwln = TUwln*v; //late night vehs
var wlnNewTc = TUwln*wlnh;
wlnNewtt = (wlnNewTc-g)/2;

var z;
z=document.frmOne.BRThrsperdp5.value;
var lnwehrs = z*TUwln;

var x;
x=document.frmOne.BRThrsperdp4.value;
var npwehrs = x*TUwln;

var totwehrs = npwehrs+lnwehrs;

var ophrs;
ophrs=(weekophrs*252)+(totwehrs*113);

f=60/h;
var pvehkm;
var pkhrs=document.frmOne.BRThrsperdp1.value;
pvehkm=veh*f*2*1*pkhrs*252;

npf=60/nph;
var wdhrs=document.frmOne.BRThrsperdp2.value;
var npvehkm;
npvehkm=p*npf*2*1*wdhrs*252;

lnf=60/lnh;
var levehkm;
levehkm=r*lnf*2*1*w*252;

var cc=nph;
cc=60/cc;
var dd=document.frmOne.BRThrsperdp4.value;
var satopvehkm;
satopvehkm=w*cc*2*1*dd*52;

var ccc=lnh;
var ccc=60/ccc;
var satlevehkm;
var ddd=document.frmOne.BRThrsperdp5.value;
satlevehkm=v*ccc*2*1*ddd*52;

var sundnpvehkm;
sundnpvehkm=w*cc*2*1*dd*61;

```

```

var sundlevehkm;
sundlevehkm=v*ccc*2*1*ddd*61;

var totalvehkm=pvehkm+npvehkm+levehkm+satopvehkm+satlevehkm+sundnpvehkm+sundlevehkm;
var maxvehsrvc=Math.max(vehs,Vehnp,Vehln);

var oc = document.frmOne.BRToc.value;
var ocg = document.frmOne.BRTocgr.value;
var period = document.frmOne.BRTp.value;
var ir = document.frmOne.BRTi.value;
if(ocg==ir)
{ocg=ocg+0.0000001;}
var ocvalue = oc*ophrs;
var ocpresent = ocvalue*((1-Math.pow((1+ocg/100),period)*Math.pow((1+ir/100),(-period)))/(ir/100-ocg/100));
var ocanual = ocpresent*(ir/100*Math.pow((1+ir/100),period))/(Math.pow((1+ir/100),period)-1);

var ec = document.frmOne.BRTe.value;
ec=Number(ec);
var ec2 = document.frmOne.BRTe2.value;
var ecg = document.frmOne.BRTegr.value;
if(ecg==ir)
{ecg=ecg+0.0000001;}
var ecvalue = ec2*ec*totalvehkm;
var ecpresent = ecvalue*((1-Math.pow((1+ecg/100),period)*Math.pow((1+ir/100),(-period)))/(ir/100-ecg/100));
var ecanual = ecpresent*(ir/100*Math.pow((1+ir/100),period))/(Math.pow((1+ir/100),period)-1);

var vc = document.frmOne.BRTvc.value;
vc=Number(vc);
var sl = document.frmOne.BRTsl.value;
sl=Number(sl);
var vcvalue = (vc)*(ir/100)/(1-1/Math.pow((1+ir/100),sl));
var vcanual = vcvalue*(period/sl)*maxvehsrvc;

var vmc = document.frmOne.BRTvmc.value;
var imc = document.frmOne.BRTimc.value;
var mcg = document.frmOne.BRTmcgr.value;
if(mcg==ir)
{mcg=mcg+0.0000001;}
var mcvalue = vmc*totalvehkm+1*imc;
var mcpresent = mcvalue*((1-Math.pow((1+mcg/100),period)*Math.pow((1+ir/100),(-period)))/(ir/100-mcg/100));
var mcannual = mcpresent*(ir/100*Math.pow((1+ir/100),period))/(Math.pow((1+ir/100),period)-1);

var sc = document.frmOne.BRTsc.value;
sc=Number(sc);
var sta = document.frmOne.BRTsta.value;
sta=Number(sta);
var scc = sc*sta;

var ic = document.frmOne.BRTinf.value;
ic=Number(ic);
var icc = (ic)*(ir/100)/(1-1/Math.pow((1+ir/100),period));
var icckm = icc*1;

var brtcost=icckm+scc+mcannual+vcanual+ecannual+ocannual;
return brtcost;
}

function MLSGraph()

```

```

{
var d1 = [];
for(var i = 500; i < (LRTMLS()+2000); i += 10)
d1.push([i, LRTAnnualCost(i)]);
var d2 = [];
for(var i = 500; i < (BRTMLS()+2000); i += 10)
d2.push([i, BRTAnnualCost(i)]);
var f = Flotr.draw($('#container'), [
{data:d1, label:'LRT', color:'#FF0000'},
{data:d2, label:'BRT', color:'blue'}
],{
xaxis:{
noTicks: 15, //Display 15 ticks
},
});
}

//Emissions Module Begins
function Country()
{
var c=document.getElementById("location").value;
if(c=='2')
{document.getElementById('canada').style.display='block';}
else{document.getElementById('canada').style.display='none';}
if(c=='1')
{document.getElementById('usa').style.display='block';}
else{document.getElementById('usa').style.display='none';}
return c;
}

function Region()
{
if(Country()=='1')
{
var r=document.getElementById("region").value;
}
if(Country()=='2')
{
var r=document.getElementById("region1").value;
}
return r;
}

function PopAffected()
{
var a = document.getElementById("popdensity").value;
var b = document.getElementById("length").value;
var c = a*b*100;
document.getElementById("popaff").value=c;
return c;
}

function LRTNOxER()

```



```

return c;
}

function LRTO2ER()
{
var a = LRTEnergyConsumption();
var a = a/1000;
var b;
if(Region()=="ASCC"){b=1.1704;}
else{if(Region()=="FRCC"){b=3.1828;}
else{if(Region()=="HICC"){b=7.8666;}
else{if(Region()=="MRO"){b=5.4775;}
else{if(Region()=="NPCC"){b=2.3936;}
else{if(Region()=="RFC"){b=8.2895;}
else{if(Region()=="SERC"){b=5.4319;}
else{if(Region()=="SPP"){b=4.1094;}
else{if(Region()=="TRE"){b=2.5557;}
else{if(Region()=="WECC"){b=1.0555;}
else{if(Region()=="Atlantic"){b=2.5139;}
else{if(Region()=="Quebec"){b=0.1187;}
else{if(Region()=="Ontario"){b=1.1044;}
else{if(Region()=="Manitoba"){b=0.0262;}
else{if(Region()=="Saskatchewan"){b=6.9646;}
else{if(Region()=="Alberta"){b=8.5206;}
else{if(Region()=="BC"){b=0.1667;}
}}}}}}}}}}}}}}
var c = a*b*(0.000454);
c=c.toFixed(2);
document.getElementById('so2output').value=c;
return c;
}

function BRTO2ER()
{
var a = BRTEnergyConsumption();
var b;
if(Region()=="ASCC"){b=0.0000023788;}
else{if(Region()=="FRCC"){b=0.0000022572;}
else{if(Region()=="HICC"){b=0.0000023788;}
else{if(Region()=="MRO"){b=0.0000023218;}
else{if(Region()=="NPCC"){b=0.0000022572;}
else{if(Region()=="RFC"){b=0.0000022572;}
else{if(Region()=="SERC"){b=0.0000022572;}
else{if(Region()=="SPP"){b=0.0000023218;}
else{if(Region()=="TRE"){b=0.0000023218;}
else{if(Region()=="WECC"){b=0.0000023788;}
else{if(Region()=="Atlantic"){b=0.000002010;}
else{if(Region()=="Quebec"){b=0.000002584;}
else{if(Region()=="Ontario"){b=0.000002584;}
else{if(Region()=="Manitoba"){b=0.000002580;}
else{if(Region()=="Saskatchewan"){b=0.000002580;}
else{if(Region()=="Alberta"){b=0.000002580;}
else{if(Region()=="BC"){b=0.000002580;}

```

```

}}}}}}}}}}}}}}
var c = a*b;
c=c.toFixed(2);
document.getElementById('so2outputBRT').value=c;
return c;
}

function LRTCO2ER()
{
var a = LRTEnergyConsumption();
var a = a/1000;
var b;
if(Region()=="ASCC"){b=1137.39;}
else{if(Region()=="FRCC"){b=1225.70;}
else{if(Region()=="HICC"){b=1552.62;}
else{if(Region()=="MRO"){b=1728.15;}
else{if(Region()=="NPCC"){b=792.99;}
else{if(Region()=="RFC"){b=1435.94;}
else{if(Region()=="SERC"){b=1371.24;}
else{if(Region()=="SPP"){b=1689.81;}
else{if(Region()=="TRE"){b=1257.28;}
else{if(Region()=="WECC"){b=998.83;}
else{if(Region()=="Atlantic"){b=586.52;}
else{if(Region()=="Quebec"){b=96.86;}
else{if(Region()=="Ontario"){b=391.04;}
else{if(Region()=="Manitoba"){b=49.57;}
else{if(Region()=="Saskatchewan"){b=1605.82;}
else{if(Region()=="Alberta"){b=1959.15;}
else{if(Region()=="BC"){b=95.27;}
}}}}}}}}}}}}}}
var c = a*b*(0.000454);
c=c.toFixed(2);
document.getElementById('co2output').value=c;
return c;
}

function BRTCO2ER()
{
var a = BRTEnergyConsumption();
var b;
if(Region()=="ASCC"){b=0.000941853;}
else{if(Region()=="FRCC"){b=0.000714138;}
else{if(Region()=="HICC"){b=0.000714138;}
else{if(Region()=="MRO"){b=0.000763929;}
else{if(Region()=="NPCC"){b=0.000714138;}
else{if(Region()=="RFC"){b=0.000714138;}
else{if(Region()=="SERC"){b=0.000714138;}
else{if(Region()=="SPP"){b=0.000763929;}
else{if(Region()=="TRE"){b=0.000763929;}
else{if(Region()=="WECC"){b=0.000941853;}
else{if(Region()=="Atlantic"){b=0.000691391;}
else{if(Region()=="Quebec"){b=0.00066976;}
else{if(Region()=="Ontario"){b=0.000667976;}

```

```

else{if(Region()=="Manitoba"){b=0.000691391;}
else{if(Region()=="Saskatchewan"){b=0.000691391;}
else{if(Region()=="Alberta"){b=0.000691391;}
else{if(Region()=="BC"){b=0.000691391;}
}}}}}}}}}}}}}}}}
var c = a*b;
c=c.toFixed(2);
document.getElementById('co2outputBRT').value=c;
return c;
}

function ShowAll()
{
LRTNOxER();
BRTNOxER();
LRTSO2ER();
BRTSO2ER();
LRTCO2ER();
BRTCO2ER();
}

//Error checking
function CheckInputsLRT()
{
if(isNaN(document.frmOne.LRTMLS.value)){alert("MLS for LRT is not a number"); return false;}
if(document.frmOne.LRTMLS.value<0){alert("MLS for LRT cannot be a negative number"); return false;}
if(isNaN(document.frmOne.LRTvo.value)){alert("Operational Speed for LRT is not a number"); return false;}
if(document.frmOne.LRTvo.value<1 || document.frmOne.LRTvo.value>100){alert("Check value for Operational Speed for LRT"); return false;}
if(isNaN(document.frmOne.LRTl.value)){alert("Length for LRT is not a number"); return false;}
if(document.frmOne.LRTl.value<1){alert("Check value for Length for LRT"); return false;}
if(isNaN(document.frmOne.LRTsta.value)){alert("Number of Stations for LRT is not a number"); return false;}
if(document.frmOne.LRTsta.value<1){alert("Check value for Number of Stations for LRT"); return false;}
if(isNaN(document.frmOne.LRThrs.value)){alert("Total Hours of Operation for LRT is not a number"); return false;}
if(document.frmOne.LRThrs.value<1 || document.frmOne.LRThrs.value>24){alert("Check value for Total Hours of Operation for LRT"); return false;}
if(isNaN(document.frmOne.LRThrsperdp1.value)){alert("Hours for Demand level 1 for LRT is not a number"); return false;}
if(document.frmOne.LRThrsperdp1.value<1 || document.frmOne.LRThrsperdp1.value>24){alert("Check value for Hours for Demand Level 1 for LRT"); return false;}
if(isNaN(document.frmOne.LRThrsperdp2.value)){alert("Hours for Demand level 2 for LRT is not a number"); return false;}
if(document.frmOne.LRThrsperdp2.value<1 || document.frmOne.LRThrsperdp2.value>24){alert("Check value for Hours for Demand Level 2 for LRT"); return false;}
if(isNaN(document.frmOne.LRTmlsratio2.value)){alert("MLS Ratio for Demand level 2 for LRT is not a number"); return false;}
if(document.frmOne.LRTmlsratio2.value<0 || document.frmOne.LRTmlsratio2.value>1){alert("Check value for MLS Ratio for Demand Level 2 for LRT"); return false;}
if(isNaN(document.frmOne.LRThrsperdp3.value)){alert("Hours for Demand level 3 for LRT is not a number"); return false;}
if(document.frmOne.LRThrsperdp3.value<1 || document.frmOne.LRThrsperdp3.value>24){alert("Check value for Hours for Demand Level 3 for LRT"); return false;}
if(isNaN(document.frmOne.LRTmlsratio3.value)){alert("MLS Ratio for Demand level 3 for LRT is not a number"); return false;}
if(document.frmOne.LRTmlsratio3.value<0 || document.frmOne.LRTmlsratio3.value>1){alert("Check value for MLS Ratio for Demand Level 3 for LRT"); return false;}
if(isNaN(document.frmOne.LRThrsperdp4.value)){alert("Hours for Demand level 4 for LRT is not a number"); return false;}
if(document.frmOne.LRThrsperdp4.value<1 || document.frmOne.LRThrsperdp4.value>24){alert("Check value for Hours for

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Demand Level 4 for LRT"); return false;}
if(isNaN(document.frmOne.LRTmlsratio4.value)){alert("MLS Ratio for Demand level 4 for LRT is not a number"); return
false;}
if((document.frmOne.LRTmlsratio4.value<0 || document.frmOne.LRTmlsratio4.value>1){alert("Check value for MLS Ratio for
Demand Level 4 for LRT"); return false;}
if(isNaN(document.frmOne.LRThrsperdp5.value)){alert("Hours for Demand level 5 for LRT is not a number"); return false;}
if((document.frmOne.LRThrsperdp5.value<1 || document.frmOne.LRThrsperdp5.value>24){alert("Check value for Hours for
Demand Level 5 for LRT"); return false;}
if(isNaN(document.frmOne.LRTmlsratio5.value)){alert("MLS Ratio for Demand level 5 for LRT is not a number"); return
false;}
if((document.frmOne.LRTmlsratio5.value<0 || document.frmOne.LRTmlsratio5.value>1){alert("Check value for MLS Ratio for
Demand Level 5 for LRT"); return false;}
if(isNaN(document.frmOne.LRTcv.value)){alert("Vehicle Capacity for LRT is not a number"); return false;}
if((document.frmOne.LRTcv.value<0 || document.frmOne.LRTcv.value>500){alert("Check value for Vehicle Capacity for LRT");
return false;}
if(isNaN(document.frmOne.Alpha.value)){alert("Capacity Utilization Coefficient for LRT is not a number"); return false;}
if((document.frmOne.Alpha.value<0 || document.frmOne.Alpha.value>2.0){alert("Check value for Capacity Utilization
Coefficient for LRT"); return false;}
if(isNaN(document.frmOne.LRTt.value)){alert("Terminal Time for LRT is not a number"); return false;}
if((document.frmOne.LRTt.value<0 || document.frmOne.LRTt.value>60){alert("Check value for Terminal Time for LRT");
return false;}
if(isNaN(document.frmOne.LRTsr.value)){alert("Vehicle Spare Ratio for LRT is not a number"); return false;}
if((document.frmOne.LRTsr.value<0 || document.frmOne.LRTsr.value>100){alert("Check value for Vehicle Spare Ratio for
LRT"); return false;}
if(isNaN(document.frmOne.LRToc.value)){alert("Operating Cost for LRT is not a number"); return false;}
if((document.frmOne.LRToc.value<0){alert("Check value for Operating Cost for LRT"); return false;}
if(isNaN(document.frmOne.LRTocgr.value)){alert("Operating Cost Growth Rate for LRT is not a number"); return false;}
if((document.frmOne.LRTocgr.value<-100 || document.frmOne.LRTocgr.value>100){alert("Check value for Operating Cost
Growth Rate for LRT"); return false;}
if(isNaN(document.frmOne.LRTE.value)){alert("Energy Consumption for LRT is not a number"); return false;}
if((document.frmOne.LRTE.value<0){alert("Check value for Energy Consumption for LRT"); return false;}
if(isNaN(document.frmOne.LRTE2.value)){alert("Energy Cost for LRT is not a number"); return false;}
if((document.frmOne.LRTE2.value<0){alert("Check value for Energy Cost for LRT"); return false;}
if(isNaN(document.frmOne.LRTegr.value)){alert("Energy Cost Growth Rate for LRT is not a number"); return false;}
if((document.frmOne.LRTegr.value<-100 || document.frmOne.LRTegr.value>100){alert("Check value for Energy Cost Growth
Rate for LRT"); return false;}
if(isNaN(document.frmOne.LRTvmc.value)){alert("Vehicle Maintenance Cost for LRT is not a number"); return false;}
if((document.frmOne.LRTvmc.value<0){alert("Check value for Vehicle Maintenance Cost for LRT"); return false;}
if(isNaN(document.frmOne.LRTimc.value)){alert("Infrastructure Maintenance Cost for LRT is not a number"); return false;}
if((document.frmOne.LRTimc.value<0){alert("Check value for Infrastructure Maintenance Cost for LRT"); return false;}
if(isNaN(document.frmOne.LRTmcgr.value)){alert("Maintenance Cost Growth Rate for LRT is not a number"); return false;}
if((document.frmOne.LRTmcgr.value<-100 || document.frmOne.LRTmcgr.value>100){alert("Check value for Maintenance Cost
Growth Rate for LRT"); return false;}
if(isNaN(document.frmOne.LRTsc.value)){alert("Station Construction Cost for LRT is not a number"); return false;}
if((document.frmOne.LRTsc.value<0){alert("Check value for Station Construction Cost for LRT"); return false;}
if(isNaN(document.frmOne.LRTinf.value)){alert("Infrastructure Construction Cost for LRT is not a number"); return false;}
if((document.frmOne.LRTinf.value<0){alert("Check value for Infrastructure Construction Cost for LRT"); return false;}
if(LRTOC()<0){alert("Exceeded limits of LRT"); return false;} //checking outputs
if(LRTEC()<0){alert("Exceeded limits of LRT"); return false;}
if(LRTVC()<0){alert("Exceeded limits of LRT"); return false;}
if(LRTMC()<0){alert("Exceeded limits of LRT"); return false;}
if(LRTSC()<0){alert("Exceeded limits of LRT"); return false;}
if(LRTICC()<0){alert("Exceeded limits of LRT"); return false;}
else
{return TotalAnnualLRTC();}

```



```

}
function CheckInputsBRT()
{
if(isNaN(document.frmOne.BRTMLS.value)){alert("MLS for BRT is not a number"); return false;}
if(document.frmOne.BRTMLS.value<0){alert("MLS for BRT cannot be a negative number"); return false;}
if(isNaN(document.frmOne.BRTvo.value)){alert("Operational Speed for BRT is not a number"); return false;}
if(document.frmOne.BRTvo.value<1 || document.frmOne.BRTvo.value>100){alert("Check value for Operational Speed for BRT"); return false;}
if(isNaN(document.frmOne.BRTl.value)){alert("Length for BRT is not a number"); return false;}
if(document.frmOne.BRTl.value<1){alert("Check value for Length for BRT"); return false;}
if(isNaN(document.frmOne.BRTsta.value)){alert("Number of Stations for BRT is not a number"); return false;}
if(document.frmOne.BRTsta.value<1){alert("Check value for Number of Stations for BRT"); return false;}
if(isNaN(document.frmOne.BRThrs.value)){alert("Total Hours of Operation for BRT is not a number"); return false;}
if(document.frmOne.BRThrs.value<1 || document.frmOne.BRThrs.value>24){alert("Check value for Total Hours of Operation for BRT"); return false;}
if(isNaN(document.frmOne.BRThrspdp1.value)){alert("Hours for Demand level 1 for BRT is not a number"); return false;}
if(document.frmOne.BRThrspdp1.value<1 || document.frmOne.BRThrspdp1.value>24){alert("Check value for Hours for Demand Level 1 for BRT"); return false;}
if(isNaN(document.frmOne.BRThrspdp2.value)){alert("Hours for Demand level 2 for BRT is not a number"); return false;}
if(document.frmOne.BRThrspdp2.value<1 || document.frmOne.BRThrspdp2.value>24){alert("Check value for Hours for Demand Level 2 for BRT"); return false;}
if(isNaN(document.frmOne.BRTmlsratio2.value)){alert("MLS Ratio for Demand level 2 for BRT is not a number"); return false;}
if(document.frmOne.BRTmlsratio2.value<0 || document.frmOne.BRTmlsratio2.value>1){alert("Check value for MLS Ratio for Demand Level 2 for BRT"); return false;}
if(isNaN(document.frmOne.BRThrspdp3.value)){alert("Hours for Demand level 3 for BRT is not a number"); return false;}
if(document.frmOne.BRThrspdp3.value<1 || document.frmOne.BRThrspdp3.value>24){alert("Check value for Hours for Demand Level 3 for BRT"); return false;}
if(isNaN(document.frmOne.BRTmlsratio3.value)){alert("MLS Ratio for Demand level 3 for BRT is not a number"); return false;}
if(document.frmOne.BRTmlsratio3.value<0 || document.frmOne.BRTmlsratio3.value>1){alert("Check value for MLS Ratio for Demand Level 3 for BRT"); return false;}
if(isNaN(document.frmOne.BRThrspdp4.value)){alert("Hours for Demand level 4 for BRT is not a number"); return false;}
if(document.frmOne.BRThrspdp4.value<1 || document.frmOne.BRThrspdp4.value>24){alert("Check value for Hours for Demand Level 4 for BRT"); return false;}
if(isNaN(document.frmOne.BRTmlsratio4.value)){alert("MLS Ratio for Demand level 4 for BRT is not a number"); return false;}
if(document.frmOne.BRTmlsratio4.value<0 || document.frmOne.BRTmlsratio4.value>1){alert("Check value for MLS Ratio for Demand Level 4 for BRT"); return false;}
if(isNaN(document.frmOne.BRThrspdp5.value)){alert("Hours for Demand level 5 for BRT is not a number"); return false;}
if(document.frmOne.BRThrspdp5.value<1 || document.frmOne.BRThrspdp5.value>24){alert("Check value for Hours for Demand Level 5 for BRT"); return false;}
if(isNaN(document.frmOne.BRTmlsratio5.value)){alert("MLS Ratio for Demand level 5 for BRT is not a number"); return false;}
if(document.frmOne.BRTmlsratio5.value<0 || document.frmOne.BRTmlsratio5.value>1){alert("Check value for MLS Ratio for Demand Level 5 for BRT"); return false;}
if(isNaN(document.frmOne.BRTcv.value)){alert("Vehicle Capacity for BRT is not a number"); return false;}
if(document.frmOne.BRTcv.value<0 || document.frmOne.BRTcv.value>500){alert("Check value for Vehicle Capacity for BRT"); return false;}
if(isNaN(document.frmOne.BRTAlpha.value)){alert("Capacity Utilization Coefficient for BRT is not a number"); return false;}
if(document.frmOne.BRTAlpha.value<0 || document.frmOne.BRTAlpha.value>2.0){alert("Check value for Capacity Utilization Coefficient for BRT"); return false;}
if(isNaN(document.frmOne.BRTtt.value)){alert("Terminal Time for BRT is not a number"); return false;}
if(document.frmOne.BRTtt.value<0 || document.frmOne.BRTtt.value>60){alert("Check value for Terminal Time for BRT"); return false;}
if(isNaN(document.frmOne.BRTsr.value)){alert("Vehicle Spare Ratio for BRT is not a number"); return false;}

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if(document.frmOne.BRTsr.value<0 || document.frmOne.BRTsr.value>100){alert("Check value for Vehicle Spare Ratio for BRT"); return false;}
if(isNaN(document.frmOne.BRToc.value)){alert("Operating Cost for LRT is not a number"); return false;}
if(document.frmOne.BRToc.value<0){alert("Check value for Operating Cost for BRT"); return false;}
if(isNaN(document.frmOne.BRTocgr.value)){alert("Operating Cost Growth Rate for BRT is not a number"); return false;}
if(document.frmOne.BRTocgr.value<-100 || document.frmOne.BRTocgr.value>100){alert("Check value for Operating Cost Growth Rate for BRT"); return false;}
if(isNaN(document.frmOne.BRTE.value)){alert("Energy Consumption for BRT is not a number"); return false;}
if(document.frmOne.BRTE.value<0){alert("Check value for Energy Consumption for BRT"); return false;}
if(isNaN(document.frmOne.BRTE2.value)){alert("Energy Cost for BRT is not a number"); return false;}
if(document.frmOne.BRTE2.value<0){alert("Check value for Energy Cost for BRT"); return false;}
if(isNaN(document.frmOne.BRTEgr.value)){alert("Energy Cost Growth Rate for BRT is not a number"); return false;}
if(document.frmOne.BRTEgr.value<-100 || document.frmOne.BRTEgr.value>100){alert("Check value for Energy Cost Growth Rate for BRT"); return false;}
if(isNaN(document.frmOne.BRTvmc.value)){alert("Vehicle Maintenance Cost for BRT is not a number"); return false;}
if(document.frmOne.BRTvmc.value<0){alert("Check value for Vehicle Maintenance Cost for BRT"); return false;}
if(isNaN(document.frmOne.BRTimc.value)){alert("Infrastructure Maintenance Cost for BRT is not a number"); return false;}
if(document.frmOne.BRTimc.value<0){alert("Check value for Infrastructure Maintenance Cost for BRT"); return false;}
if(isNaN(document.frmOne.BRTmcgr.value)){alert("Maintenance Cost Growth Rate for BRT is not a number"); return false;}
if(document.frmOne.BRTmcgr.value<-100 || document.frmOne.BRTmcgr.value>100){alert("Check value for Maintenance Cost Growth Rate for BRT"); return false;}
if(isNaN(document.frmOne.BRTsc.value)){alert("Station Construction Cost for BRT is not a number"); return false;}
if(document.frmOne.BRTsc.value<0){alert("Check value for Station Construction Cost for BRT"); return false;}
if(isNaN(document.frmOne.BRTinf.value)){alert("Infrastructure Construction Cost for BRT is not a number"); return false;}
if(document.frmOne.BRTinf.value<0){alert("Check value for Infrastructure Construction Cost for BRT"); return false;}
if(BRTOC<0){alert("Exceeded limits of BRT"); return false;} //checking outputs
if(BRTEC<0){alert("Exceeded limits of BRT"); return false;}
if(BRTVC<0){alert("Exceeded limits of BRT"); return false;}
if(BRTMC<0){alert("Exceeded limits of BRT"); return false;}
if(BRTSC<0){alert("Exceeded limits of BRT"); return false;}
if(BRTICC<0){alert("Exceeded limits of BRT"); return false;}
else
{return TotalAnnualBRTCost();}
}

</script>
<style type="text/css">
.style2 {
text-align: left;
font-family: "Gill Sans MT";
}
.style3 {
font-size: small;
font-family: Latha;
}
.style4 {
text-decoration: underline;
}
.style6 {
font-family: "Gill Sans MT";
color: #0071BD;
font-size: xx-large;
}

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.style7 {
font-family: "Gill Sans MT";
}
.style8 {
font-family: "Gill Sans MT";
color: #000080;
font-size: medium;
}
.style9 {
border: 5px solid #CC0000;
font-family: "Gill Sans MT";
}
.style10 {
text-align: center;
font-family: "Gill Sans MT";
}
.style11 {
text-align: center;
}
</style>

</head>
<body>
<h2 class="style6">Santiago and Casello Model</h2>
<h4 class="style8"><a href="Documents/Sensitivity_Analysis.xls">Click here to
download Sensitivity Analysis</a></h4>
<h4 class="style7">&nbsp;  Input Values </h4>
<p class="style3"><em>*Please enter the values below in its corresponding
space. Numerical values only.</em></p>
<form name = "frmOne">
<table style="width: 75%" class="style7">
<tr>
<td style="width: 200px">&nbsp;  </td>
<td style="width: 100px" class="style4"><strong>LRT</strong></td>
<td class="style4" style="width: 100px"><strong>BRT</strong></td>
</tr>
<tr>
<td style="width: 200px; height: 61px;"><a href="" class="more" title="Maximum passenger volume in the maximum load
section along the line.">
Passenger Demand for Maximum Load Section (pass/hr):</a></td>
<td style="width: 100px; height: 61px;">
<input type="text" name="LRTMLS" value="1500" onkeyup="document.frmOne.BRTMLS.value = this.value;" size="10"
style="width: 82px"/></td>
<td style="width: 100px; height: 61px;">
<input type="text" name="BRTMLS" value="1500" size="10" style="width: 82px"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Average speed of a transit unit along the line. Travel speed offered
to the public.">
Operational Speed (Vo = km/hr):</a></td>
<td style="width: 100px"><input type="text" name="LRTvo" value="45"size="10"/></td>
<td style="width: 100px"><input type="text" name="BRTvo" value="25"size="10"/></td>
</tr>

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<tr>
<td style="width: 200px"><a href="" class="more" title="One-way distance from one terminal to the other along the
alignment.">
Length (km):</a></td>
<td style="width: 100px"> <input type="text" name="LRTl" value="15" onkeyup="document.frmOne.BRTl.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTl" value="15" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Facilities for passenger boarding/alighting, waiting, and transfer.">
Number of Stations:</a></td>
<td style="width: 100px">
<input type="text" name="LRTsta" value="10" onkeyup="document.frmOne.BRTsta.value = this.value" size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTsta" value="10" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Total hours a day the system will operate.">
Total Hours of Operation:</a></td>
<td style="width: 100px"> <input type="text" name="LRThrs" value="18" onkeyup="document.frmOne.BRThrs.value =
this.value" size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRThrs" value="18" size="10"/></td>
</tr>
<tr>
<td style="width: 200px">Hours per Demand Period:</td>
</tr>
<tr>
<td style="width: 200px"><em>Demand Level 1 (Peak):</em></td>
<td style="width: 100px"> <input type="text" name="LRThrsperdp1" value="6"
onkeyup="document.frmOne.BRThrsperdp1.value = this.value" size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRThrsperdp1" value="6" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>Demand Level 2 (Off-Peak):</em></td>
<td style="width: 100px"> <input type="text" name="LRThrsperdp2" value="9"
onkeyup="document.frmOne.BRThrsperdp2.value = this.value" size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRThrsperdp2" value="9" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>MLS Ratio for Level 2:</em></td>
<td style="width: 100px">
<input type="text" name="LRTmlsratio2" value="0.8" onkeyup="document.frmOne.BRTmlsratio2.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTmlsratio2" value="0.8" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>Demand Level 3 (Late Evening):</em></td>
<td style="width: 100px"> <input type="text" name="LRThrsperdp3" value="3"
onkeyup="document.frmOne.BRThrsperdp3.value = this.value" size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRThrsperdp3" value="3" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>MLS Ratio for Level 3:</em></td>
<td style="width: 100px">

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<input type="text" name="LRTmlsratio3" value="0.6" onkeyup="document.frmOne.BRTmlsratio3.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTmlsratio3" value="0.6" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>Demand Level 4 (Weekend Day):</em></td>
<td style="width: 100px">
<input type="text" name="LRThrsperdp4" value="9" onkeyup="document.frmOne.BRThrsperdp4.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRThrsperdp4" value="9" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>MLS Ratio for Level 4:</em></td>
<td style="width: 100px">
<input type="text" name="LRTmlsratio4" value="0.8" onkeyup="document.frmOne.BRTmlsratio4.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTmlsratio4" value="0.8" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>Demand Level 5 (Weekend Evening):</em></td>
<td style="width: 100px">
<input type="text" name="LRThrsperdp5" value="4" onkeyup="document.frmOne.BRThrsperdp5.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRThrsperdp5" value="4" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><em>MLS Ratio for Level 5:</em></td>
<td style="width: 100px">
<input type="text" name="LRTmlsratio5" value="0.6" onkeyup="document.frmOne.BRTmlsratio5.value = this.value"
size="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTmlsratio5" value="0.6" size="10"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Number of spaces for passengers that a vehicle offers.">
Vehicle Capacity:</a></td>
<td style="width: 100px"> <input type="text" name="LRTcv" size="10" value="220"/></td>
<td style="width: 100px"> <input type="text" name="BRTcv" size="10" value="120"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Also known as the Load Factor. Ratio of utilized capacity or number
of passengers per spaces">
Capacity Utilization Coefficient:</a></td>
<td style="width: 100px"> <input type="text" name="Alpha" size="10" value="0.8"/></td>
<td style="width: 100px"> <input type="text" name="BRTAlpha" size="10" value="0.8"/></td>
</tr>
<tr>
<td style="width: 200px">
<a href="" class="more" title="Time spent by a transit unit at a terminal.">
Terminal Time:</a></td>
<td style="width: 100px"> <input type="text" name="LRTtt" size="10" onkeyup="document.frmOne.BRTtt.value = this.value"
value="5"/></td>
<td style="width: 100px"> <input type="text" name="BRTtt" size="10" value="5"/></td>
</tr>

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<tr>
<td style="width: 200px"><a href="" class="more" title="Percentage of spare vehicles available.">
&nbsp;&nbsp;&nbsp;Vehicle Spare Ratio:</a></td>
<td style="width: 100px"> <input type="text" name="LRTsr" size="10" value="10"/></td>
<td style="width: 100px"> <input type="text" name="BRTsr" size="10" value="10"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Costs related to the operation of the system, for example wages. ">
Labor Cost ($/hr):</a></td>
<td style="width: 100px"> <input type="text" name="LRToc" size="10" value="25"/></td>
<td style="width: 100px"> <input type="text" name="BRToc" size="10" value="20"/></td>
</tr>
<tr>
<td style="width: 200px">Operating Cost Growth Rate(%):</td>
<td style="width: 100px"> <input type="text" name="LRTocgr" size="10" onkeyup="document.frmOne.BRTocgr.value =
this.value" value="2"/>%</td>
<td style="width: 100px"> <input type="text" name="BRTocgr" size="10" value="2"/>%</td>
</tr>
<tr>
<td style="width: 200px">
<a href="" class="more" title="Vehicle energy consumption">
Energy Consumption (kwh/km) or (L/km):</a></td>
<td style="width: 100px">
<input type="text" name="LRTe" size="10" value="3.6"/></td>
<td style="width: 100px"> <input type="text" name="BRTe" size="10" value="1.32"/></td>
</tr>
<tr>
<td style="width: 200px">
<a href="" class="more" title="Costs related to energy consumption">
Energy Cost:</a></td>
<td style="width: 100px">
&nbsp;&nbsp;&nbsp;</td>
<td style="width: 100px"> &nbsp;&nbsp;&nbsp;</td>
</tr>
<tr>
<td style="width: 200px"><em>&nbsp;&nbsp;&nbsp;Electricity Cost ($/kwh):</em></td>
<td style="width: 100px">
<input type="text" name="LRTe2" size="10" value="0.12"/></td>
<td style="width: 100px"> &nbsp;&nbsp;&nbsp;</td>
</tr>
<tr>
<td style="width: 200px"><em>&nbsp;&nbsp;&nbsp;Diesel Cost ($/L):</em></td>
<td style="width: 100px"> &nbsp;&nbsp;&nbsp;</td>
<td style="width: 100px"> <input type="text" name="BRTe2" size="10" value="0.90"/></td>
</tr>
<tr>
<td style="width: 200px">Energy Growth Rate(%):</td>
<td style="width: 100px"> <input type="text" name="LRTegr" onkeyup="document.frmOne.BRTegr.value = this.value"
size="10" value="2"/>%</td>
<td style="width: 100px"> <input type="text" name="BRTegr" size="10" value="2"/>%</td>
</tr>
<tr>

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<td style="width: 200px">Vehicle Capital Cost ($):</td>
<td style="width: 100px"> <input type="text" name="LRTvc" size="10" value="4500000"/></td>
<td style="width: 100px"> <input type="text" name="BRTvc" size="10" value="750000"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Expected lifetime or use of the vehicle">
Service Life (Years):</a></td>
<td style="width: 100px"> <input type="text" name="LRTsl" size="10" value="30"/></td>
<td style="width: 100px"> <input type="text" name="BRTsl" size="10" value="12"/></td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Time period over which the alternatives are going to be analyzed.">
Period:</a></td>
<td style="width: 100px"> <input type="text" name="LRTp" onkeyup="document.frmOne.BRTp.value = this.value" size="10"
value="40"/></td>
<td style="width: 100px"> <input type="text" name="BRTp" size="10" value="40"/></td>
</tr>
<tr>
<td style="width: 200px; height: 26px;">Interest Rate (%):</td>
<td style="width: 100px; height: 26px;"> <input type="text" name="LRTi" onkeyup="document.frmOne.BRTi.value =
this.value" size="10" value="5"/>%</td>
<td style="height: 26px; width: 100px;">
<input type="text" name="BRTi" size="10" value="5"/>%</td>
</tr>
<tr>
<td style="width: 200px"><a href="" class="more" title="Costs related to maintenace of vehicles, facilities and
infrastructure">
Maintenance Cost:</a></td></tr>
<tr><td style="width: 200px"><em>Vehicle Maintenance: ($/veh-km)</em></td>
<td style="width: 100px"> <input type="text" name="LRTvmc" size="10" value="0.5"/></td>
<td style="width: 100px"> <input type="text" name="BRTvmc" size="10" value="0.3"/></td>
</tr>
<tr><td style="width: 200px"><em>Infrastructure Maintenance: ($/km)</em></td>
<td style="width: 100px">
<input type="text" name="LRTimc" size="10" value="120000"/></td>
<td style="width: 100px"> <input type="text" name="BRTimc" size="10" value="100000"/></td>
</tr>
<tr>
<td style="width: 200px">Maintenance Growth Rate (%):</td>
<td style="width: 100px"> <input type="text" name="LRTmcgr" size="10" onkeyup="document.frmOne.BRTmcgr.value =
this.value" value="2"/>%</td>
<td style="width: 100px"> <input type="text" name="BRTmcgr" size="10" value="2"/>%</td>
</tr>
<tr>
<td style="width: 200px">Station Construction Cost ($/Station):</td>
<td style="width: 100px"> <input type="text" name="LRTsc" size="10" value="500000"/></td>
<td style="width: 100px"> <input type="text" name="BRTsc" size="10" value="500000"/></td>
</tr>
<tr>
<td style="width: 200px">Infrastructure Construction Cost ($/km):</td>
<td style="width: 100px"> <input type="text" name="LRTinf" size="10" value="30000000"/></td>
<td style="width: 100px"> <input type="text" name="BRTinf" size="10" value="15000000"/></td>
</tr>

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</table>
<p><span class="style7"><a href="" class="more" title="Check if LRT vechiles are going to be coupled.">
LRT Coupling?:</a></span><input type="checkbox" name="coupling" size="10" value="Coupling" class="style7"/></p>
<p>&nbsp;<strong><span class="style7">Output (Annual Costs)</span></strong></p>
<table style="width: 75%" class="style9">
<tr>
<td style="width: 200px">Labor Cost:</td>
<td style="width: 100px"><input type="text" name="LRTOperatingCost" size="10" value="" /></td>
<td style="width: 100px"><input type="text" name="BRTOperatingCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 200px">Energy Cost:</td>
<td style="width: 100px"><input type="text" name="LRTEnergyCost" size="10" value="" /></td>
<td style="width: 100px"><input type="text" name="BRTEnergyCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 200px">Vehicle Cost:</td>
<td style="width: 100px"><input type="text" name="LRTVehicleCost" size="10" value="" /></td>
<td style="width: 100px"><input type="text" name="BRTVehicleCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 200px">Maintenance Cost:</td>
<td style="width: 100px"><input type="text" name="LRTMaintenanceCost" size="10" value="" /></td>
<td style="width: 100px"><input type="text" name="BRTMaintenanceCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 200px; height: 30px">Station Construction
Cost:</td>
<td style="height: 30px; width: 100px"><input type="text" name="LRTStaConstructionCost" size="10" value="" /></td>
<td style="height: 30px; width: 100px;"><input type="text" name="BRTStaConstructionCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 200px">Infrastructure Construction Cost:</td>
<td style="width: 100px"><input type="text" name="LRTInfCost" size="10" value="" /></td>
<td style="width: 100px"><input type="text" name="BRTInfCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 200px">&nbsp;</td>
</tr>
</table>
<br />
<table style="width: 75%" class="style9">
<tr>
<td style="width: 300px">Total Annual Cost:</td>
<td style="width: 100px">&nbsp;<input type="text" name="LRTTotalAnnualCost" size="10" value="" /></td>
<td style="width: 100px"><input type="text" name="BRTTotalAnnualCost" size="10" value="" /></td>
</tr>
<tr>
<td style="width: 300px">&nbsp;</td>
<td style="width: 100px">
<input type="button" name="b2" value="LRT Total Annual Cost" onclick="CheckInputsLRT()" style="width: 152px"
class="style7"/></td>

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<td style="width: 100px">
<input type="button" name="b5" value="BRT Total Annual Cost" onclick="CheckInputsBRT()" style="width: 152px"
class="style7"/></td>
</tr>
</table>
<strong><br />
<br />
<br />
<br />
<span class="style7">Other Output </span> </strong>
<table style="width: 75%">
<tr>
<td style="width: 340px" class="style7">Energy Consumption: </td>
<td style="width: 130px">&nbsp;<input type="text" id="LRTeneConsump" name="LRTeneConsump" size="10" value=""
class="style7"/><span class="style7"><em>kwh</em></span></td>
<td style="width: 130px">
<input type="text" name="BRTeneConsump" id="BRTeneConsump" size="10" value="" class="style7"/><span
class="style7"><em>L</em></span></td>
</tr>
<tr>
<td style="width: 340px" class="style7">&nbsp;</td>
<td style="width: 130px">
<input type="button" name="b7" value="LRT Energy Consumption" onclick="LRTEnergyConsumption()" style="width:
165px" class="style7"/></td>
<td style="width: 130px">
<input type="button" name="b8" value="BRT Energy Consumption" onclick="BRTEnergyConsumption()" style="width:
159px" class="style7"/></td>
</tr>
</table>
<br class="style7" />
<span class="style7">
<strong>Annual Cost Graph</strong></span><br class="style7" />
<input type="button" name="b6" value="Graph" onclick="RadarGraph()" style="width: 100px" class="style7"/>
<br class="style7" />
<br class="style7" />
<br class="style7" />
</form>
<div class="style10"><canvas id="radar1" width="450" height="300">[No
canvas support]</canvas>
</div>
<br class="style7" /><center class="style7"></center>
<br class="style7" />
<span class="style7"><strong>Frequency (veh/hr)</strong></span><br class="style7" />
<input type="button" name="b11" value="Graph" onclick="BarGraph()" style="width: 100px" class="style7"/><br
class="style7" />
<div style="text-align:center">
<span class="style7">
<canvas id="bar1" width="450" height="200">[No canvas support]</canvas></span>
<span class="style7">
<canvas id="bar2" width="450" height="200">[No canvas support]</canvas>
</span>
</div>

```

```

<br class="style7" />
<br class="style7" />
<span class="style7">
<strong>MLS* - Equal Demand and Annual Cost for both modes:</strong></span><br class="style7"/>

<input type="button" name="graph" value="Graph" onclick="MLSGraph()" class="style7"/><br class="style7"/>
<br class="style7"/>
<br class="style7" />
<span class="style7">Annual Cost ($)</span><center><div id="container" style="width:800px;height:400px;"></div>

<p class="style10" style="width: 798px">MLS (Pass/hr)</p>
</center>

<p class="style10" style="width: 798px">&nbsp;</p>
<p class="style2" style="width: 798px">&nbsp;</p>

<br class="style7" />
<br class="style7" />
<br class="style7" />

<span class="style7">Select Country for Analysis:</span><br class="style7" />
<select id="location" name="country" onchange="Country()" class="style7">
<option></option>
<option value="1">USA</option>
<option value="2">Canada</option>
</select><br class="style7" />
<br class="style7" />
<br class="style7" />
<span class="style7">

</span>

<form>
<div id="canada" style="display:none;"><center></center>
<br/>
<span class="style7" /> Select Region of Analysis:<br class="style7" />
<select name="menu2" id="region1" onchange="Region();">
<option value="0"></option>
<option value="Atlantic">Atlantic (East)</option>
<option value="Quebec">Quebec (Central)</option>
<option value="Ontario">Ontario (Central)</option>
<option value="Manitoba">Manitoba(West)</option>
<option value="Saskatchewan">Saskatchewan(West)</option>
<option value="Alberta">Alberta(West)</option>
<option value="BC">BC(West)</option>
</select>
</div>

<div id="usa" style="display:none;"><center></center>
<br/>
<br/>
Select Region of Analysis:<br/>
<select name="menu2" id="region" onchange="Region();">
<option value="0"></option>
<option value="ASCC">ASCC</option>

```



```
class="style7" /><br class="style7" />
<br class="style7" />
<br class="style7" />
<br class="style7"/>

</form>
<div class="style7">
Copyright ©; 2013 by Deborah Santiago. All rights reserved.
</div>
</body>
</html>
```