TRAVEL TIME MODELLING IN TRANSIT ORIENTED NEIGHBOURHOODS OF TORONTO, MONTREAL AND VANCOUVER:

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS FOR TRANSPORTATION (GIS-T)

by

Nebojsa Stulic

Bachelor of Arts in Geographic Analysis

Ryerson University, 2014

A Major Research Paper presented to Ryerson University

in partial fulfillment of the requirements for the degree of

Master of Spatial Analysis

in the program of Spatial Analysis

Toronto, Ontario, Canada, 2020

AUTHOR'S DECLARATION FOR ELECTRONIC SUBMISSION OF AN MRP

I hereby declare that I am the sole author of this MRP. This is a true copy of the MRP, including any required final revisions.

I authorize Ryerson University to lend this MRP to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this MRP by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

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

Abstract

TRAVEL TIME MODELLING IN TRANSIT ORIENTED NEIGHBOURHOODS OF TORONTO, MONTREAL AND VANCOUVER:

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS FOR TRANSPORTATION (GIS-T)

Master of Spatial Analysis (MSA), Ryerson University, 2020
Nebojsa Stulic

This research offers spatial analysis of travel times by public transit and automobile in transit oriented neighbourhoods of Toronto, Montreal and Vancouver. These neighbourhoods are defined by 400 and 800 metre walking distance buffers from major rail transit stations. Study implemented array of GIS-T techniques analyzing origin-destination travel matrices producing six commuting scenarios and presented results with descriptive statistics, spatial analysis and linear regression models. The optimal transit models were the ones where trips originate and end in neighbourhoods around transit stations. Overall transit trips in Toronto and Montreal were comparable, while in Vancouver significantly longer than those by automobile. Segmenting models by trip length showed more pronounced differences. For 10-kilometre trips transit commute times were longer by 15 % in Toronto; 6 % in Montreal; and 52 % in Vancouver, than trips made by automobile. Modal travel time disparity decreased with trip lengths and increased by distance from transit stations.

Acknowledgements

I owe gratitude to numerous individuals for their guidance, support, and help in this research.

First and foremost, Professor Murtaza Haider is recognised for his intellectual and moral support, which made this research possible. The successful completion of this paper would not have been possible without his dedication.

I am extremely grateful to researchers at McGill University, Boer Cui and Professor Ahmed El-Geneidy, for kindly sharing their data as well as their sound advice along the way.

I would also like to extend my deepest gratitude to Dr. Howard Slavin of Caliper Corporation® for the continuous support of Urban Analytics Institute at Ryerson University and providing TransCAD software which was instrumental in this research. Furthermore, I would also like to acknowledge Paul Ricotta for his technical assistance with TransCAD.

I am deeply indebted to Professor Shuguang Wang for his friendship and unwavering support over the years. Many thanks to Professor Evan Cleave for serving as a member of the committee and his invaluable insights.

My most sincere appreciation goes to Lynette Clugston for her continuous encouragement. Lastly, none of this would be possible without true love from my parents and my brother.

Table of Contents

Appendices

List of Tables

List of Figures

List of Appendices

CHAPTER 1 INTRODUCTION

1.1 Background and justification for the research

Urban transit planning discourse, globally, has been predominantly to shift commuters off cars and on to public transit. Canadian metropolitan centres, which have been expanding rapidly, are following identical planning philosophies. However, investment in public transit has been in discordance with the needs and demands required to adequately service the rapidly growing population of urban areas in the last few decades. Lack of efficient transit services have contributed over time to longer commutes and increased traffic congestion, which is not only detrimental to the environment, but also costs Canada’s economy billions of dollars in lost productivity.

To improve and expand public transit systems across Canada, the federal budget has promised billion-dollar investments in 2018–19 to be provided through a Public Transit Infrastructure Fund to improve commutes, cut air pollution, strengthen communities and grow Canada's economy (Infrastructure Canada, 2019). Funding is being provided to support a few areas of the public transit domain ranging from the rehabilitation and updates of public transit systems; the planning of future system improvements and expansions; enhanced asset management; active transportation projects; and system optimization and modernization (Infrastructure Canada, 2018). The plan specifically pledges to cut commute times allowing Canadian commuters to get to and back from work on time and spend more time with their families. Significance of commute times is best highlighted by recent comments from the renowned transportation professor and researcher, Eric Miller: "when we are assessing different transportation policies, we look at the time people spend commuting" (Bennardo, 2019).

Justification of these transit investments is evidenced by higher numbers of commuters and increased reliance on public transit indicated by the greatest proportion of commuters that use public transit than ever before in Canada. Since 1996, the number of total commuters has risen by 3.7 million or 30.3%, to 15.9 million in 2016 (Statistics Canada, 2017). In the same time period, the number of commuters taking public transit grew by 59.5%, while those using a car increased by 28.3%. In 2016, nearly three-quarters of all working Canadians lived in a CMA which is where much of Canada's public transit infrastructure and investments are found (Statistics Canada, 2017).

According to latest data from Statistics Canada transit commuters in Canada spend far more time travelling to and from work than those who commute by car. Nationally, transit commutes are 86-percent longer than those made by automobile (Statistics Canada, 2017). In 2016, the average commuting time was 24.1 minutes for car and 44.8 minutes for public transit.

Travel time comparisons in large Canadian Census Metropolitan areas (CMA's), which would intuitively be expected to have smaller differences due to factors such as built transit infrastructure and higher ridership rates, are also showing significantly pronounced disparity between the two travel modes. For instance, in Vancouver, travel to work by car takes on average 27.3 minutes while commuting by public transit takes on average 43.6 minutes. Montreal public transit commuters spend on average 44.4 minutes in traffic, while average commutes to work by car take 26.8 minutes. In Toronto the average commutes are slightly longer with public transit commutes being completed in 49.5 minutes and those by car in 30.3 minutes (Statistics Canada, 2017).

Hence the commute to work data challenges the notion that building more public transit will save travel time by shifting commuters from cars to public transit. The objective of the aforementioned investments will undoubtedly lead to new transit infrastructure projects; and make necessary improvements in current ones such as better signalling and track equipment for rail-based transit, and transit priority lanes for surface transit (Haider, 2018). The question remains if these improvements and new transit infrastructure investments will reduce travel times by public transit, making it a more attractive option to commuters.

1.2 Research problem and hypotheses

This paper, based on the assumptions and statistics that public transit commute trips are slower than those made by private automobile, is looking at origin-destination trip matrices for the three most populous Canadian Census Metropolitan Areas of Toronto, Montreal and Vancouver to analyze relative travel times between transit and automobile to determine whether there are locations from which transit trips might be comparable or faster than by automobile. The explores the issue by asking: "Are commutes by transit faster than automobile for neighbourhoods near transit stations?".

The hypothesis is that transit commutes in the neighbourhoods near major rail stations are either faster or highly comparable to car commutes, depending on the trip origin and destination scenarios, and trip lengths. Special focus will be on trips from and to neighbourhoods around transit stations as they would potentially exhibit fastest transit travel times due to the use of fastest public transit travel mode (subway, metro or light rail).

1.3 Potential benefits

Information will potentially prove valuable in the urban transit planning sphere by shedding light on nuances and different scenarios of travel to work data and associated trip characteristics such as distances traveled. It can have important implications in public transit planning, especially since cities are increasingly adopting Transit Oriented Developments and Transit Oriented Neighbourhoods in their official planning policies to stop sprawl, by either building more housing developments, or improving current ones in the neighbourhoods around transit stations. As our cities are expanding and urban form is becoming denser, shifting the majority of people from a longer form of commute to slower might prove to be increasingly difficult and illogical. However, if the communities close to transit have comparable travel times then the incentive to use public transit, and motivation behind building, improving and living in transit-oriented neighbourhoods, would be greater.

1.4 Outline of the report

This research project starts with the introduction of the topic in Chapter 1 followed by literature review of academic research on the subject in Chapter 2. Variable definitions, calculations and methodology is discussed in Chapter 3. Additional focus in the methodological section of Chapter 3 is given to the review of academic and planning literature which supported methodological procedures of buffer segmentation choices, and Geographic Information Systems for Transportation (GIS-T) techniques adopted in the study. This is followed by Chapter 4 where detailed analysis is carried out by implementing three main techniques for each city: descriptive statistics, maps and regression analysis. Conclusions and recommendations are briefly presented in Chapter 5. Research is supported throughout by use of maps and tabular data (Chapters 3 and 4). Appendices A and B carry supplementary analytical maps and detailed regression tables to support the main analytical text of Chapter 4, in which they have been referred to.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a broader review of the academic literature on the research topic. It is divided thematically into two main parts. First portion addresses travel characteristics and trends associated with areas around transit stations defined in literature as Transit - Oriented Developments. It also includes imperative factors and determinants of travel mode choices in these neighbourhoods for commuters. The focus then shifts to travel times. Initial comparisons of relevant studies and findings are addressed noting differences between automobile and transit commutes in urban context. This section additionally addresses other crucial aspects of travel times, most notably how investments are affecting them, and their associations with vital aspects of our lives such as economy and health.

Important definitions of the terms applied in the research are explained in appropriate sections. It should be noted that there is an additional review of relevant research later in the project, in a more suitable section relating to methodological steps to support and justify the procedural choices in the study.

2.2 Travel Characteristics and Mode Determinants in TOD

Geographic extent in our research is based on travel characteristics for the areas around major transit stations. These areas, in academia and planning agendas, are defined as Transit-Oriented Developments. A Transit-Oriented Developments (TOD) is a type of development which is designed mainly to encourage the use of public transit and create a pedestrian-friendly urban environment (Nasri & Zhang, 2014). TOD focuses, as mentioned by Renne et al. (2005), on compact mixed-use urban growth within an easy 5-10-minute walk to transit stations, bringing potential riders closer to transit facilities, and promotes increased transit ridership. It has been further acknowledged by Thomas et al. (2018) that TODs have been embraced in many cities and regions worldwide either conceptually or by directly implementing it in their design and planning scenarios.

In the United States, state legislatures, have direct involvement in administering and financing TOD projects. At least 22 states, are asserting their role in shaping policies that support TOD near existing and planned transit lines and stations, and making investments in them to develop new infrastructure to support transit (Shinkle, 2012).

In another more detailed definition, we can see that TODs can include both new developments and existing neighbourhoods, and are accordingly classified in three main categories as: (1) new TODs, developed around new public transportation services; (2) high-density TODs, where new public transportation services are provided in existing, compact, mixed-use areas; and (3) low-density TODs, in which the density and diversity of existing, suburban-style neighbourhoods adjacent to public transportation services are increased (De Vos, Van Acker & Witlox, 2014).

However, TODs are most often associated with new construction or redevelopments (of either one or more buildings) whose design and orientation facilitate transit use (California Department of Transportation, 2002). Therefore, the terms transit-oriented development and transit-oriented neighbourhood (or transit-oriented communities) are intermittently used in the study denoting the same concept, with the former prevalently referenced in the literature review while the latter in the remaining sections. The reasoning behind this decision is that transit-oriented neighbourhoods (or transit-oriented communities) are terms that would instinctively include older and established higher density neighbourhoods around transit stations, along with the ones representing new developments and revitalization projects often associated with TOD perceptions.

Since our study is comparing two most common travel modes, transit and automobile, it is imperative to understand factors that are affecting these choices. Factors affecting transit usage and travel mode choices commonly encountered in the literature are costs, availability, access, land use variables, mode travel time, transit service factors (cost, comfort, etc.) and socio-economic and demographic variables. Racca and Ratledge (2003) grouped them into five broad categories: travel mode level of service (LOS); accessibility; land use and urban design; transit users' socioeconomic and demographic characteristics; and characteristics of the trip.
The focus in the literature review has been on those relevant to the research, more specifically land use variables, travel time and trip characteristics.

There is a substantial body of academic literature that focuses on explanations and causal relationships between built environments and travel mode choices, in general, as well as in TOD context. The studies in this area have been prolific and extensive forcing few comprehensive reviews of the published literature. Ewing and Cervero (2010) provided detailed meta-analysis, or a systematic way of combining information from around sixty transportation research studies, common and consistent built form variables were identified that influence travel behaviour and modal choice. These factors are density, diversity, design, destination accessibility, and distance to transit. The authors identified that proximity to transit has been specifically strong determinant of modal choice. All these determinants can be associated with transit-oriented neighbourhoods, yet the two that are directly and intrinsically related to them are *density* and *distance to transit*. Distance to transit, as TODs are spatially defined by the areas around transit station; and density, as many common TOD definitions are including it in their specifications while constantly attempting to increase it.

A fair amount of academic research has supported the notion that density in TOD can have positive effects on public transit trip characteristics. In one study, the likelihood that a Bay Area station-area resident commuted by rail was 24.3% at densities of 10 residential units per gross acre. Doubling densities to 20 units per acre increased the likelihood to 43.4% and quadrupling them to 40 units per acre catapulted the probability to 66.6% (National Academies of Sciences, Engineering, and Medicine, 2004). In another study in the United States, doubling of density was associated with nearly a 60% increase in transit boardings (Parsons Brinckerhoff Quade and Douglas Inc, 1995).

Distance to transit, on the other hand, is a more important built form factor in our study as it represents the variable that was directly used to define buffers around the stations. Also, it is intuitive reasoning that residents who either live or work near transit stations will use it more frequently. In that respect research was able to quantify these assumptions. Lund, Cervero and Willson (2004) found that California transit station area residents are about five times more likely to commute by transit than the average worker in the same city. Many other cities have reported high statics as well. In the Washington (D.C.) Metropolitan Area and Toronto that likelihood increases seven to eight times as high, versus the other commuters in the same respective cities (National Academies of Sciences, Engineering, and Medicine, 2004; Stringham, 1982).

Nevertheless, proximity to transit does pose a specific bias, often referred to as *self-selection bias*. It states that living within a walking distance to a transit line is the primary reason for choosing resident location in the first place (Guo and Chen, 2007). Since self-selection bias suggests peoples‘ residential choice is influenced by their preferences in living and commuting in areas around transit stations it becomes challenging to unravel some of the effects of the built environment, such as proximity to transit, on travel. Usually the studies that attempt to control for the self selection bias would devise survey type data collection to determine the responses regarding individual residential decisions before moving, and then aggregate them.

The rates of transit participation, regardless of self selection, are high for residents who live near transit stations, and they gradually decrease with distance. For example, within one-quarter mile of stations, transit captured between 20 percent (in California) and 60 percent (in Canada) of all work trips (Cervero, 1993; Bernick & Cervero, 1997). These participation rates can be much higher for segments of transit routes, or specific stations, as illustrated by the examples derived from United States transportation surveys. In one such instance at the Randolph Towers near Arlington County's Ballston Station, 69% of residents commuted to work via transit, compared with a regionwide transit mode share of just 9% (National Academies of Sciences, Engineering, and Medicine, 2004). There are urban areas that have even higher associated rate of ridership for people who live near transit. For instance, the Hong Kong population census data revealed that remarkably 82.7% of residents within 400 m from a Mass Transit Railway (MTR) station use public transportation system for commuting trips while 81.1% of residents within longer 800–1200 m distance from a MTR station do so as well (Hong Kong Census and Statistics Department, 2018).

Consensus in transportation literature is that most transit trips are work related. Linking this information to proximity to transit and its influence on travel behaviours led to research which proposed that transit stations located near workplaces are more effective than stations near residences (Tsai, 2009). It suggests for a stronger emphasis on the non-residential components of transit developments, such as retail and employment. Additional research in Denver, Colorado showed similar results, that if the work destination is near a transit station area, commuters are more likely to take public transit as measured by more trips and more distances travelled (Kwoka, Boschmann & Goetz, 2015). Observations since the 1970s have indicated that there has been a stable increasing trend in transit share of work trips in TODs in the United States (Renne, 2005).

Moreover, and very importantly for our research, was the study conducted in Chicago which showed that a large percentage of trips that originate from households close to transit also terminate at work destinations close to transit (Lindsey, Schofer, Durango-Cohen & Gray, 2010). The relevance to our research is that geographic concertation is on trips that also start and end in the areas around transit stations, hypothesizing comparative or faster transit times than those made by car. Similarly comparing TOD to Non-TOD zones of the Washington (D.C.) Metropolitan Area showed that the probability of choosing transit mode is higher for trips originating and ending in TOD areas. However, the magnitude of the TOD effect in this study was larger at trip origin than destination (Nasri & Zhang, 2019). This type of commute scenario, of traveling from and to transit oriented neighbourhoods, was captured in the suggestion that the ideal planning strategy is the one which emphasized location of both residential areas and employment centers around transit stations (Cervero, 1996).

Proximity to transit is by its nature tied to the assumption that commuters will walk to transit stations. It has been supported by empirical evidence that transit passengers tend to walk significantly farther (nearly twice as far on average) to access rail stations than bus stops (Daniels & Mulley, 2011). Therefore, the mode of the public transit was identified as the most important determinant of walking distance for transit commuters. As our research is focused on areas around rail stations, the higher motivation of commuters to walk to nearest station is valuable information. The authors attributed these differences to the types of services provided: rail tends to be faster, has more attractive stations (often including amenities), serves longer trips (rail trips average about twice the distance), and are more dispersed, forcing passengers to walk farther to access train stations.

As previously noted, TOD can take few urban forms, mostly as a new development or established neighbourhood, raising the question whether these would affect walking to transit in different ways. Lu et al. (2018) have conducted an interesting study (which was able to control for self selection bias) in Hong Kong comparing walking behaviors in established urban neighborhoods versus new transit-oriented towns (equivalent to new suburban developments around rail transit stations in the western cities). The results showed new town residents walked less for transportation purposes than urban residents in areas around transit stations.

However, the new town residents living close to MTR station had similar transportation walking frequencies and distances compared to with those living further from MTR stations, (as defined by 400m and, 800-1200 m buffers). Authors do add that Hong Kong has well-developed public transportation systems, and low private car ownership in contrast to most Western cities, which would influence residents living far from MTR to still heavily rely on walking or public transit for transportation trips.

Of interest to our study was also the review that addresses trip distance in TODs, as it was one of the variables used in the research. It should be noted, to highlight the importance of trip distances, that policy makers generally use vehicle miles traveled (VMT) to measure the amount of travel for all vehicles in a geographic region over a given period. It is the aggregated measurement calculated as the sum of the number of miles traveled by each vehicle. In context of transit-oriented development, shifting people from automobiles to transit being one of the main objectives, VMT serves as a measure of transportation performance of number and length of vehicle trips. Effective TOD performance would be reflected in lower VMT values characterized by fewer and shorter trips, while also showing increases in number of transit trips (Alarcon, Cho, Degerstrom, Hartle & Sherlock, 2018).

Trip distances in our research are individual representations between each trip origin and destination calculated as the shortest path on a road network. The research by Zamir et al. (2014) offers some insightful results in how similar types of disaggregated trip distances are reflected in TOD areas in Washington, D.C., and Baltimore. It showed that TOD is associated with shorter trip lengths, with an overall higher level of trip generation and increased transit ridership. TOD residents took transit more often than residents of non–TOD zones, and their trips were, on average, 25% to 40% shorter in length than those of residents of non-TODs.

In another study investigating the relationship between travel modes of TOD users and their personal and transit characteristics in Brisbane, Australia, the TOD users showed lesser odds of choosing public transport for greater trip lengths. Interestingly, for shoppers, odds of making longer public transit trips were better (Muley, Bunker, & Ferreira, 2009). It additionally illustrates that trip purpose can also have an impact in travel mode decisions and trip length characteristics.

2.3 Travel Time

2.3.1 Travel Time Definitions

Travel time, as broadly defined by Turner et al. (2018), is "the time necessary to traverse a route between any two points of interest" , and is composed of running time, or time in which the mode of transport is in motion, and stopped delay time, or time in which the mode of transport is stopped (or moving sufficiently slow as to be stopped, i.e., typically less than 8 kph). Stopped delay time is generally associated with traffic control devices and congestion. For public transit, travel time also includes dwell times at stops, which in congested systems can constitute a major source of delay (Meyer & Institute of Transportation Engineers, 2016).

Accounting for congestion is an especially important factor to capture realistic travel scenarios prevalent in urban areas for certain travel time periods. Based on the time of the day of travel these are defined as *peak* or *off-peak* hours. While their definitions might differ based on the type of the area (downtown, residential, etc.), incoming and outgoing traffic flows, they are generally characterized as: *morning peak period* (encompasses all congestion during the peak morning commute, typically sometime between the hours of 6 a.m. and 9 a.m.), *evening peak period* (encompasses all congestion during the peak evening commute, typically sometime between the hours of 4 p.m. and 7 p.m.) and *off-peak period* (includes periods of free-flow traffic during the middle of the day or late in the evening, typically between 10 a.m. and 11 a.m., 1 p.m. to 3 p.m., or after 7 p.m.) (Turner et al. 1998).

Meyer et al. further adds an important travel time related concept named *portal-to-portal travel time*, or alternatively encountered in literature as *door-to-door travel time*. It includes in-vehicle time (time actually spent traveling) and out-of-vehicle time (time spent waiting for transit service, transferring to another vehicle, and time spent in walking between the vehicle and the origin and destination at both ends of the trip). In literature distances and times that a person walks to the first, and from the last stop, are frequently referred to as *access* and *egress*.

Door-to-door was the approach predominantly implemented in this study. Car travel time in the research was estimated by Google Application Programming Interfaces (API); and the public transit was calculated from General Transit Feed Specification (GTFS), for *peak-hour* at 8 am.

Estimates were representing travel from the centroid locations of origin to centroid locations of destination (census tracts were geographic unit).

Both car and transit models used fastest route algorithm accounting for congestion in *peak-hour* scenarios, with an additional *off-peak* car model. Public transit adopted true *portal-to-portal* approaches as it is inherently included in GTFS calculations, and it includes up-to-date public transport schedules, transfers, waiting times, fastest transit mode and realistic route combinations (GTFS, n.d.-b). Additionally, the walking portion of the trip was included as well (access and egress), representing the walk from the origin to the first transit stop, and from the last transit stop to the destination (GTFS, n.d.-b). While a subsequent section addressing methodology will elaborate on some of these concepts in more detail, it is relevant to mention them in the literature review section in the context of travel time definitions.

2.3.2 Travel Time Comparisons between Public Transit and Auto

Few comparable studies were encountered in literature assessing relative travel time differences between car and public transit. The most comprehensive one, and by its preliminary design framework and type of the research question addressed relevant to our research, was conducted for the Greater Helsinki Area, Finland. The authors, Salonen and Toivonen (2013), in order to make travel time estimates comparable between travel modes, estimated trips between centroids of the 6,900 grid cells serving as trip origins (250 m by 250 m cells corresponded to the Grid Database of Statistics Finland), and 59 public libraries as destinations (explained as libraries are representing one of the most actively used public services in Finland).

Authors also devised three different scenarios of travel time calculations based on various levels of trip characteristics involved in computations. Their intermediate and advanced models are assessed as most analogous to ours for interpretation, and consequently comparison, of the results. The Helsinki's intermediate car model accounted for congestion but ignored parking, and the intermediate transit model incorporated schedule data in a simplistic way (Salonen & Toivonen, 2013). The advanced car model included congestion and parking; while transit estimates accounted for congestion, routing and true schedules.

The results show that absolute differences in car and public transit travel times are notable in the Greater Helsinki area, no matter which models are used for comparison. However, there were some geographical and model dependent differences which the authors discovered. In the intermediate model average travel times by car was 28.9, and by transit 53.8 minutes, with larger differences encountered along ring roads and in downtown. The average travel times were 2.05 times longer by public transit outside city centre, and 1.94 longer in the city centre.

In the advanced model, authors observed average travel time by car at 34.4 and by public transit at 55.7 minutes, with smallest differences between the two modes in downtown and along railway lines. The largest differences were observed along outer ring roads. In the city centre the model showed transit trips to be 1.39 longer, and outside of the city centre 1.63 times longer. Geographical distribution indicated that the city centre area has a considerable concentration of low ratios, meaning that in the advanced model public transit travel times are fairly competitive in relation to car travel times. Other areas of low differences are found along the railway lines. The largest differences are concentrated along the edges of the study area, indicating that travelling by public transit from these areas to the destinations is much slower than travelling by car.

In another study by Benenson et al. (2011) differences between public transit and car were evaluated in the Tel Aviv metropolitan area, by the slightly different methodology of *accessibility*. Accessibility measures achievement of travel objectives within time limits, therefore, travel time is a modifier or the primary performance measure (Turner et al. 1998). In this particular study the objective pertinent to our research was car and transit access for service areas comparisons.

Authors calculated travel times by including various detailed parameters such as time of the travel, congestion, waiting times, access and egress' walking speeds and distances. The results found that the Tel Aviv metropolitan area showed large gaps between car and transit-based accessibility despite a dense bus network in the city. They attributed these large gaps to the distinction between direct trips and trips with transfers, emphasizing on inclusion of waiting times and transfers in the analysis of public transit travel times.

2.3.3 Travel Time and Infrastructure Investment

The level of the current investments in public transit infrastructure in Canada was briefly mentioned in the introductory section of the paper. Globally every city is either investing in some forms of new transportation infrastructure or improving the current one. As the cities are continuing to invest in transit infrastructure researchers have found little evidence over the years whether there are travel time savings as a result of this. Travel time is recognized as one of the largest costs of transportation, and travel time savings are often the primary justification and greatest expected benefit for transportation infrastructure improvements (Victoria Transport Policy Institute [VTPI], 2016).

In its comprehensive review of theory and practice in transportation planning literature regarding travel time savings and its impact on economic benefits through cost-benefit analysis and other approaches, Metz (2008) concludes the value of investment in transport infrastructure lies mainly in the additional access to desirable locations made possible and that the benefits of such access involves diminishing marginal utility (the additional benefit from access to any particular kind of location would tend to decline as choice increases). The author mentions that the level of investment in Britain in the 20-year period (prior to 2008) was between £3.5 and £6.4 billion per year (at constant 2004/05 prices) and that average travel time (which has been constant in Britain during that period) would have been higher in the absence of new road construction.

Other researchers have also confirmed that building additional road infrastructure does not necessarily lead to reduction of total travel times in cities. Teodorovic and Janic (2016) mention that addition of the new link (roadways) in the network even if it is a wrong location would not increase average travel times, if distributed through the network according to the system optimum principles.

The opposite might be true as well, that removing roads may advance traffic conditions and decrease travel times. The authors add that there are some countries that recently significantly invested in expressway networks, and simultaneously increased average commute time.

In terms of the travel time costs (time spent traveling multiplied by unit costs) between two main travel modes of transit and automobile, they are generally lower for high quality public transit than for driving, even if transit travel takes more minutes per trip. For example, if transit travel is comfortable travel costs are estimated to average 25% of wage rates, compared with 50% or more of wage rates for driving under congested conditions (VTPI, 2016). Victoria Transport Policy Institute (2016) in their detailed evaluation of travel time cost studies across the globe which also estimated travellers' willingness-to-pay for travel time savings (i.e. road tolls in North America, reduced passenger per square meter in public transit in Sweden, etc.) concluded that travellers would generally pay more for travel time savings.

Based on another review of international studies evaluating transportation improvements for international development (Gwilliam, 1997), it was suggested that work travel time should be valued at wages and benefits, and that a default value for adult personal travel (including commuting) travel time should be 30% of household income per hour unless better local data are available. The above noted examples indicate the importance that is placed on travel time value as a parameter for evaluating transport projects. The domain of transport economics and cost benefit analysis has in part been defined by the value of travel time savings, because the economic benefits deriving from better transport are transferred beyond the transport domain into the wider economy (Metz, 2008).

It is supported by evidence that shorter travel time will also increase ridership by public transit. For example, when Los Angeles County Metropolitan Transportation Authority (MTA) unveiled bus rapid transit (BRT) on two corridors in the region (Shinkle, 2012), time savings during peak hours increased between 10 and 35 percent, with significant increases in ridership of 26 percent and 33 percent (a third of the increase was due to new transit riders), demonstrating directly how new infrastructure investments can positively impact transit services in relatively short time frames.

2.3.4 Travel Time, Health and Economic Factors

While the focus of the study was not to measure nor quantify economic and health factors it is of crucial importance to mention them to highlight the importance that travel time has on economic policies and health factors including established negative health externalities.

In recent years, a considerable amount of literature has contributed to our understanding on how increased travel times associated with congestion and longer commutes (45 to 90 minutes and longer) are detrimentally affecting our health. In the meta analysis of the academic literature on the subject wide-ranging health issues have been noted (Batchelor, 2016).

They are grouped in five broad categories which are (including some conditions and symptoms) *:* *physical health* (obesity, black carbon exposure, higher blood pressure, diabetes mellitus, lower cardiorespiratory fitness); *mental health* (chronic and increased stress, depression, lower sense of well being), *activities* (reduction in sleeping, physical activity and food preparation which over time contribute to obesity and poorer health; less physical exercise; fewer sleeping hours), *work performance* (increased sickness absence, longer average paid time loss days, fewer working hours, more accidents, lower job satisfaction and decreased intention to stay with same employer), and *social life* (less access to social capital, social isolation, higher time and strain based work life conflict, strain on relationships and likelihood of divorce, low social participation and low general trust). Motivation to decrease travel times would certainly reap many health benefits across these conditions.

Economic impacts for the same regions as the study areas in our research have been recorded as well. Metrolinx (2008) estimated that the economic cost of congestion in the Greater Toronto and Hamilton Area (GTHA) to commuters was $ 3.3 billion (including increased commuting costs, accidents, emissions, and delays) and the annual cost to the economy was $2.7 billion (including reduced employment, increased operating expenses, and reduced industry revenues). Under current trends, the cost of congestion experienced by GTHA residents is forecast to increase considerably by 2031, resulting in an increase in costs from $3.3 billion per year to $7.8 billion.

Vancouver metropolitan area estimated that the hidden costs of congestion are between $500 million and $1.2 billion a year (Dachis, 2015). Improving public transit times and as a result increasing ridership would contribute significantly to lowering congestion, delays and emissions leading to lower associated annual costs to commuters and economy.

Furthermore, reducing driving and improving other modes of transportations can provide various economic, social and environmental benefits. The study in Massachusetts showed that each one percentage point reduction in vehicle travel will provide $ 20 billion worth of savings and benefits for the State's residents over a 15-year period (Batchelor, 2016). This study concentrated solely on economic impacts excluding benefits such as lower carbon emissions and public health benefits. The author concludes that applying similar projections based on population numbers in Metro Vancouver area could result in savings of $1.12 billion Canadian dollars per year .

2.4 Gaps in Literature

Extensive reports on TOD stated that transit mode share can vary from 5% to nearly 50% citing the primary reason for this range is that transit use is heavily influenced by relative travel times with automobile, and extensiveness of transit service (National Academies of Sciences, Engineering, and Medicine, 2008). The report further adds that relative travel time (transit versus auto) is more important than any land use factor (density, diversity of uses, design) in ridership.

However, voluminous empirical literature encountered on TOD subject is based on the analysis of land use factors and their relations and effects on travel mode choices and travel characteristics, without sufficient research on travel times despite its stated importance in TOD context.

Previous sections demonstrated the importance of travel times in many spheres of transportation planning and their impacts on infrastructure investments, economy and health. Studies which compare relative travel times between different modes (automobile and transit) are generally concentrated on accessibility measures and reliability of travel time calculations. The relevant study by Salonen & Toivonen (2013) offered some insights in relative modal differences however not in TOD context.

There has been limited recognition of empirical comparison between relative travel times between public transit and automobile in urban areas. Therefore, the purpose of this paper is to quantify and compare relative travel times in a Canadian urban context to assess their comparability in transit-oriented neighbourhoods.

CHAPTER 3 METHODOLOGY

3.1 Study Context

The objective of the study is to determine and compare travel times for public transit versus automobile travel in transit-oriented communities of three Canadian major urban centres: Toronto, Montreal and Vancouver. The geographic extent of the research focused on the aforementioned cities in order to highlight places in Canadian context having rapid transit system infrastructure and established public transit operations, which would enable objective comparisons between public transit and car travel. These transit systems are Toronto subway, Montreal Metro and Vancouver's rapid light rail system, referred to as SkyTrain. Transit system details are summarized in Table 3.

The methodological procedure involved comparing relative travel times between transit and automobile to determine whether there are locations from which transit trips might be comparable or faster than by automobile. The focus was on the neighbourhoods near transit stations as they would presumably have the fastest transit times in all the census metropolitan regions, leading to the hypothesis that trips originating or ending in them would have comparable or improved travel trip characteristics in time and distance to those in the same neighbourhoods made by car.

The information could be of potentially vital importance and relevance in urban and transit planning, as cities are moving their agendas and philosophies towards transit-oriented communities and developments advocating living and working near transit stations with increased transit usage, and reduced commuter times and distances (Suzuki, Cervero & Iuchi, 2013).

3.2 Data and Geographic Study Areas

The data type used in the research were Origin-Destination (O-D) pairs describing spatial interactions between origins and destinations, with each pair being analogous for a set of movements. It is a common spatial data structure in various transportation studies (Rodrigue et al. 2013), as well as in more complex travel forecast and demand estimation models, which can range from traditional four-stage and emerging activity-based models predicting the trip-making behavior of the population, to gravity model of trip distribution (Hensher, 2016).

The data have been represented in two formats: O-D pairs and matrix cells, also known as origin - destination matrix, where rows are related to the centroid locations of origin, while columns are related to centroid locations of destination.

Analysis used census tract as the unit of geography to estimate origin-destination travel flows for all census tract pairs. These were obtained for congested travel time for all three metropolitan regions with starting point at 8 am for public transit and car, as well as vehicle travel time during off-peak hours. Transit travel time adopted calculations from scheduled travel from GTFS data for the year 2017, leaving at 8 am. In this manner, the data between public transit and car could be compared using same parameters, time frames, accounting for congestion and peak-hour scenarios.

Research models and travel time data estimations were applied to three geographic study regions delineated by Central Metropolitan Areas (CMAs) boundaries for Toronto (Figure 1), Montreal (Figure 2) and Vancouver (Figure 3). The Toronto study area additionally included Hamilton and Oshawa CMAs to better represent interconnected, populous and homogeneous regions representing the urban part of the Greater Golden Horseshoe commonly associated with it.

The Toronto study area was largest in comparison measuring 8581 square kilometres with 1426 census tracts which created a travel matrix of 2,033,476 corresponding pairs; the Montreal area was calibrated at 4661 square kilometres and 970 census tracts making up 940,900 origin-destination travel pairs; while the Vancouver study region represented the smallest of the three consisting of 3801 square kilometres and 476 census tracts constructing 225,626 origin-destination cells (Table 1).

Table 1: Study Area Origin-Destination Trip Records

Census Metropolitan Region	Origin-Destination Travel Time Matrix Records	Census Tract Records
Toronto (including Hamilton and Oshawa)	2,033,476	1,426
Montreal	940,900	970
Vancouver	225,626*	476*

Note: There are 475 census tracts for Vancouver CMA included in the calculation of O-D matrix, with additional census tract 9330181.15 which has been originally excluded due to its specific status. The census tract describes the Semiahmoo Indian Reserve located on the eastern section of Boundary Bay, also known as Semiahmoo Bay. Due to this detail, the size of the O-D Travel Time matrix for Vancouver is 225,626 records, which represents a regular matrix square root calculation for 475 census tracts with one more added census tract for the Semiahmoo Indian Reserve.*

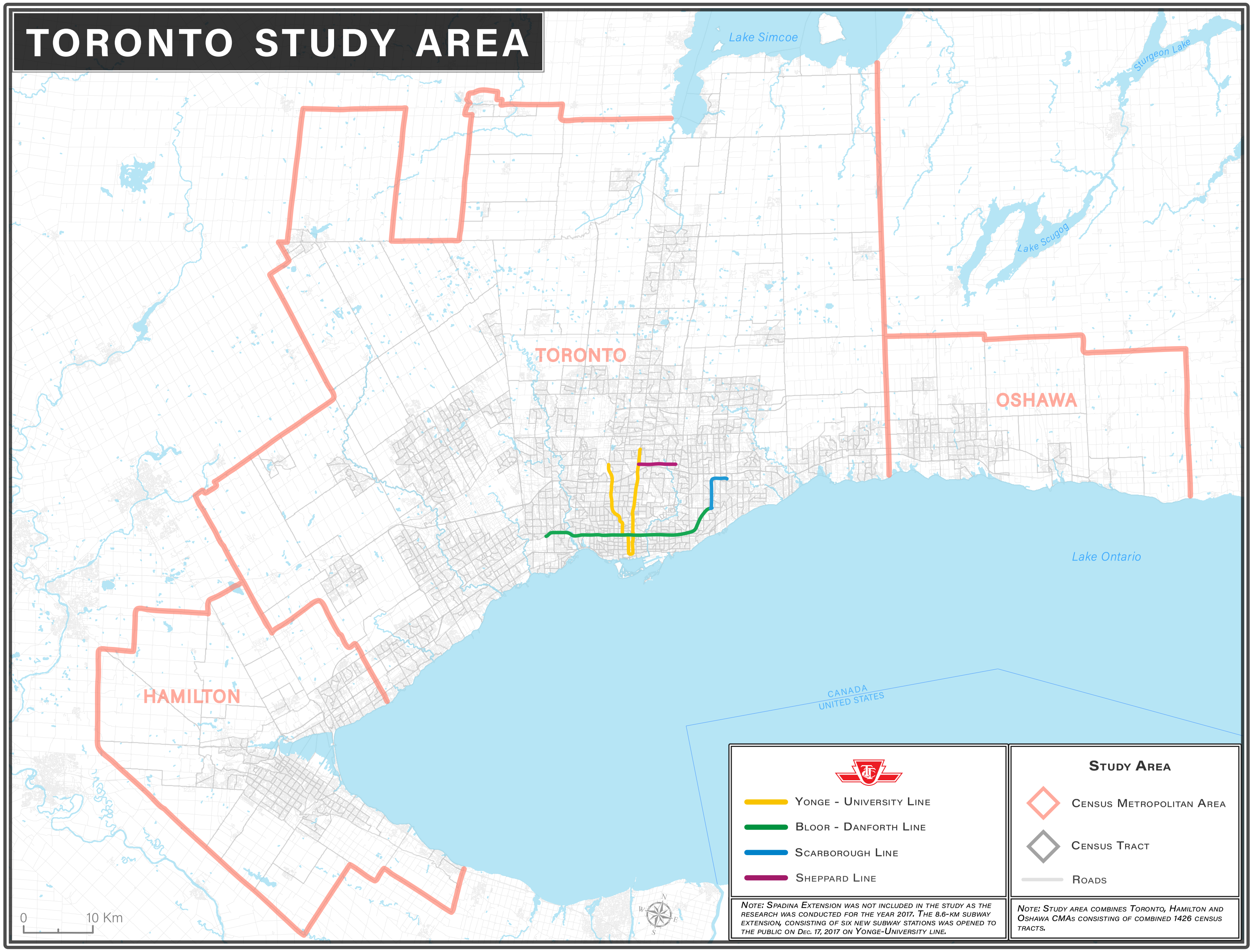


Figure 1: Toronto Study Area

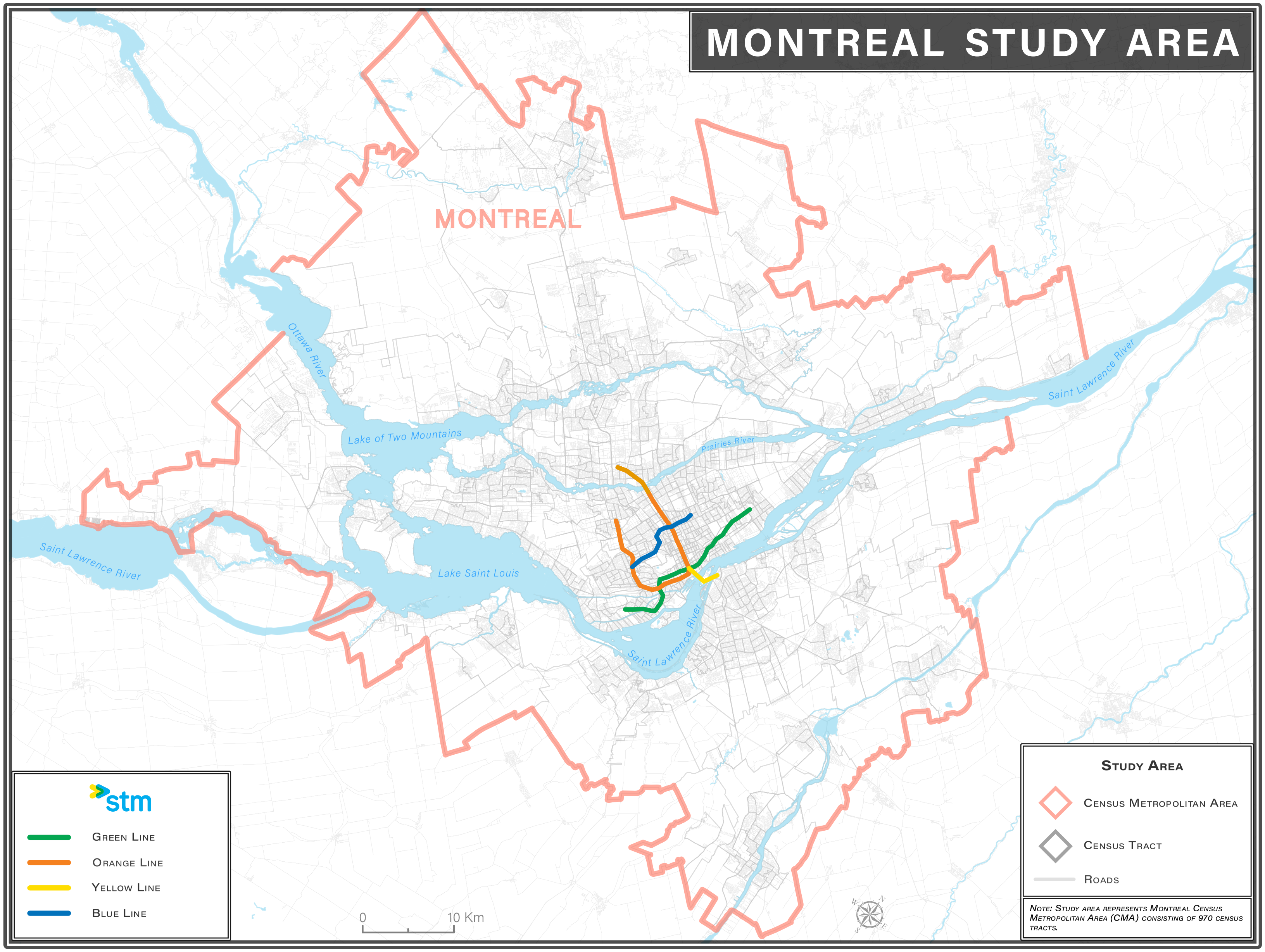


Figure 2: Montreal Study Area

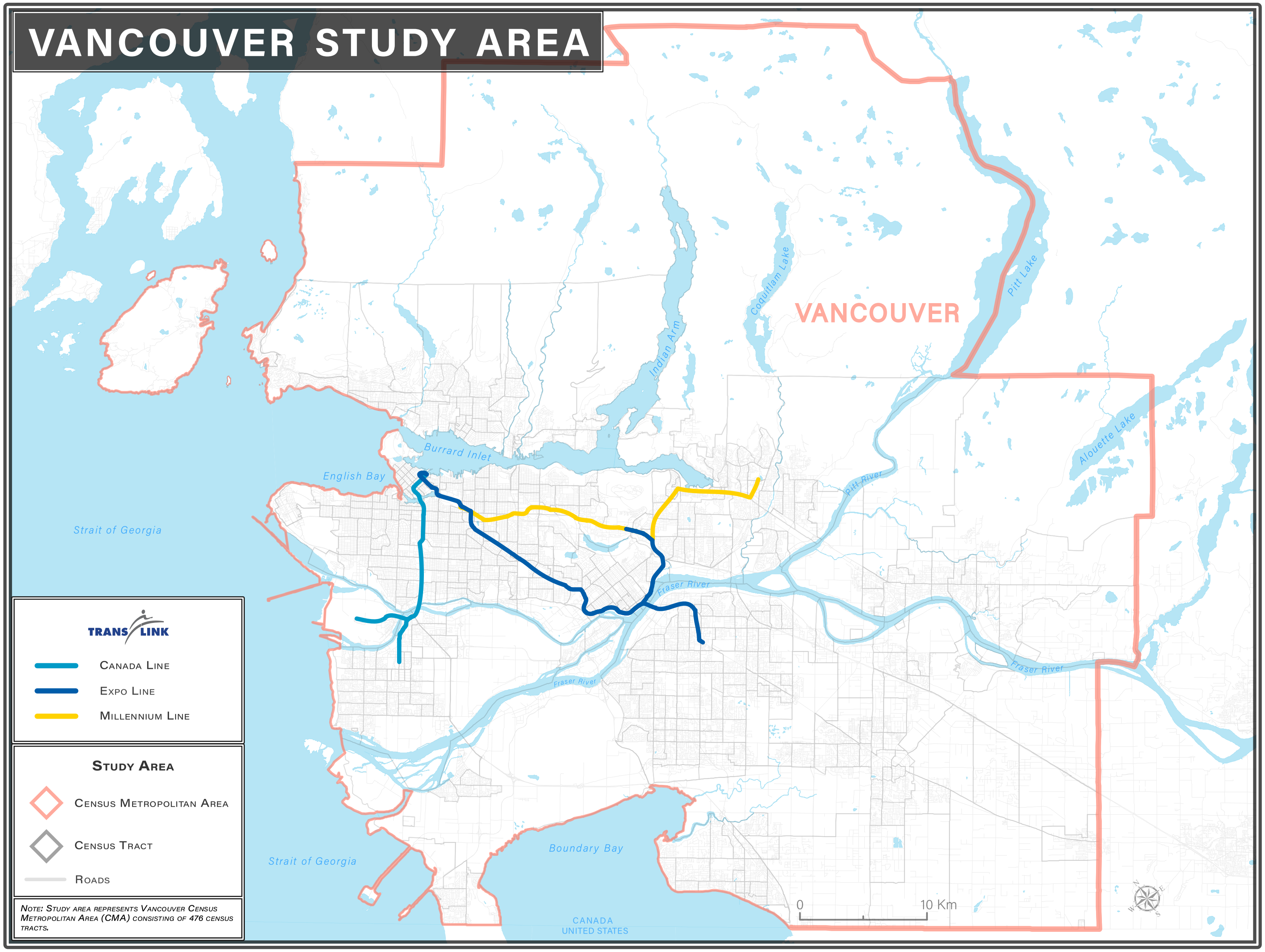


Figure 3: Vancouver Study Area

Data sets were obtained from McGill University (El-Geneidy & Cui, 2019) using census tracts as the geographic unit and represented as pairs travelling from and to each census tracts (csv format). The methodology implemented for public transit travel times was the previously mentioned GTFS while car travel calculation used Google Maps API taking advantage of readily available and dynamically updated transportation network data (El-Geneidy & Cui, 2019). It should be noted that the calculation of O-D travel time matrix is a common task in GIS applications and commercial vendors already have specific automated extensions for these tasks. For instance, ArcGIS Network Analyst module is a common tool which requires users to load road networks and define common parameters in order to calibrate origin-destination matrices and its characteristics are expressed as travel time and distance (ESRI, n.d.). However, implementing Google Maps API has a few advantages, mainly in using more updated road data, accounting for road congestion and routing rules, and has the ability to differentiate between peak and off-peak hours (Wang & Xu, 2011).

There were four calculated variables in the study expressing measures between each pair of origin and destination census tract. These were: transit travel time, car travel time during peak hours while accounting for congestion, car travel time during off-peak hours, and distance. The exact names and measuring units of the variables are listed in Table 2.

Table 2: Summary of Variables

Variable Name	Variable Description	Unit
Transit Travel Times 8 AM	Public transit travel time during peak hours at 8 am	Minutes/Seconds (min/sec)
Car Travel Time Peak Hours	Car travel time at peak hours accounting for congestion	Minutes/Seconds (min/sec)
Car Travel Time Off Peak Hours	Car travel time at off-peak hours	Minutes/Seconds (min/sec)
Distance Car	Distance between census tracts when traveling by car	Metres (m)

Note: Car travel time was determined using Google Maps Application Programming Interface (API) and transit travel time was calculated for scheduled travel from General Transit Feed Specification (GTFS) data for the year 2017 leaving at 8 am.

3.2.1 Toronto Subway System

The Toronto transit system, operated by the Toronto Transit Commission (TTC), is responsible for providing public transit in the City of Toronto. In 2017, the subway system consisted of 69 stations and four lines (Figure 5). It is made up of mostly larger heavy rail which operates on all lines except the Scarborough RT which utilizes light rapid transit with smaller, fully automated, medium capacity trains. The subway system transported 216 million passengers in 2017, with subway trains accounting for 213 million and Scarborough RT for 3 million yearly passengers (Toronto Transit Commission, n.d.-a).

The four subway lines measured a total route length of 68.3 km in 2017 (Table 3). Estimates have shown that average daily subway ridership levels in 2017 were slightly shy of 1 million riders, as measured on an average weekday basis (American Public Transportation Association, 2017-a)**.**

The Toronto-York Spadina Subway Extension (TYSSE), a six-station, 8.6-km extension of the Yonge-University line, was omitted from the study as it was opened to the public at the end of the research year, more particularly on December 17, 2017 (Toronto Transit Commission, n.d.-b). Correspondingly TYSSE was not included in public transit travel time calculations referred to in the previous section about data.

The geographic file for TTC subway routes was obtained directly from the open data portal (City of Toronto Open Data, 2018). Transit stops were plotted by creating a GIS compatible file from the most recent GTFS TTC data feed which was subsequently edited to exclude the TYSSE (Open Mobility Data, 2019).

3.2.2 Montreal Metro System

Montreal Metro system is served by the local transit agency, Société de transport de Montréal (STM), and is comprised of 68 stations and four metro (Figure 6, Table 3) lines (Société de transport de Montréal, n.d.-a). It consists of a heavy rail train type which runs entirely underground and was the first subway in North America to run on rubber tires instead of metal wheels (Gilbert, 2016).

The city exhibits high public transit usage. American Public Transportation Association Transit Ridership Report estimated in 2017 that Montreal ranked second in North America (excluding Mexico) in public transit ridership measures right after New York, with 1.2 million average unlinked daily trips (Table 3), measured on weekday basis (American Public Transportation Association, 2017-b)**.** The same public transit association reported Montreal having phenomenal annual ridership rates with 367 million completed trips in 2017.

Geographic files for Montreal Metro lines and stations were created from GTFS feeds available through STM open data developer portal (Société de transport de Montréal, n.d.-b).

3.2.3 Vancouver Rapid Transit Rail System

Vancouver's SkyTrain is the oldest and one of the longest automated driverless light rapid transit systems in the world that runs on a mostly elevated guideways (Translink, n.d.). TransLink, transportation authority is responsible for planning, financing and managing transportation modes and services in the Metro Vancouver region of British Columbia. It also uses subsidiary BC Rapid Transit Company to maintain and operate two of the three SkyTrain lines in Metro Vancouver: the Expo Line and the Millennium Line (Wales, 2008). In total, SkyTrain consists of three routes, the third one being the Canada Line, and 53 stations (Figure 7, Table 3), (Translink, n.d.).

Average weekly ridership, based on an average weekday for the second quarter in 2017, was 468 000 (American Public Transportation Association, 2017). SkyTrain had estimated annual ridership of 151 million in the year 2017 (American Public Transportation Association, 2018).

Geographical transit data was obtained from University of British Columbia ABACUS Public Data Collection (Lesack, 2019).

Table 3: Rapid Transit Rail Systems in Canada

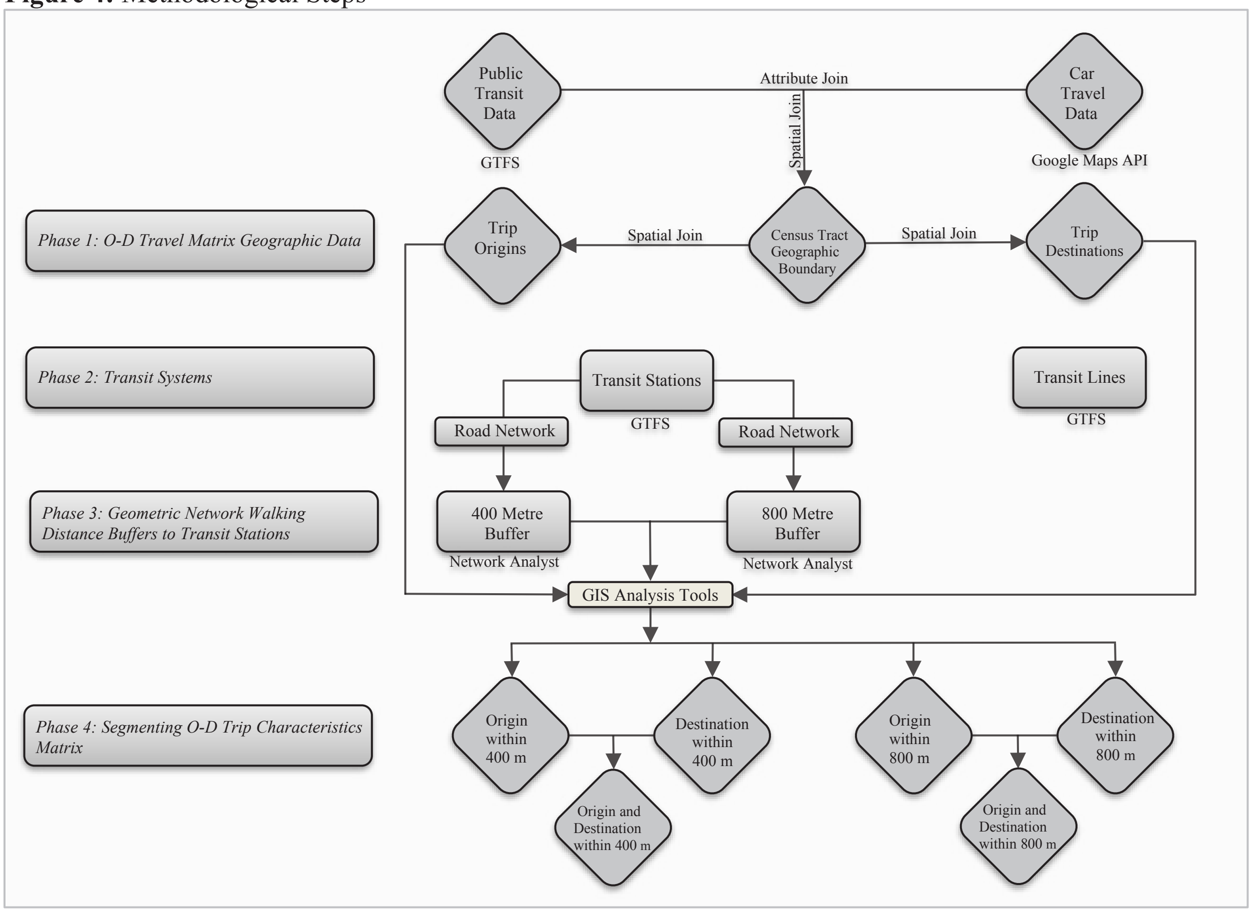
	Toronto Subway	**Montreal Metro**	**Vancouver SkyTrain**
Transit Stations	69[1]	68	53
Transit Routes Number	4	4	3
Transit Network Extent	68.3 km	66.1 km	79.8 km
Transit Lines Length	Yonge – University 30.2 km	Green 22.1 km	Expo 35.0 km[4]
	Bloor – Danforth 26.2	Orange 30.0 km	Millennium 25.3 km[4]
	Sheppard 5.5 km	Yellow 4.25 km	Canada 19.5 km
	Scarborough RT 6.4 km	Blue 9.7 km	
Yearly Ridership [2017] [2]	533 million	367 million	151 million
Average Daily Ridership [2017] [3]	986,000	1,181,000	468,000
Rail Type	Heavy Rail, Light Rapid Transit[5]	Heavy rail	Light Rapid Transit

Note [1]: Toronto Transit stations for Toronto are not accounting for the Spadina Extension (TYSSE) as the research is conducted for the year 2017 before its opening. Note [2]: Yearly Ridership is based on total system ridership for year 2017. Information for Montreal and Vancouver is reported by American Public Transportation Association Ridership Report, Second Quarter, 2017. Yearly ridership for Toronto is reported by TTC. TTC combined subway and LRT ridership is 216 million. Note [3]: Average Daily Ridership is based on daily ridership during Average Weekday from American Public Transportation Association Ridership Report, Second Quarter, 2017. Ridership is based on unlinked passenger trips which are counted each time a passenger boards rapid transit rail regardless whether it is fare, pass or transfer. Note [4]: Expo and Millennium Lines share 1.8 km of route length. Note [5]: Scarborough RT is the only subway line in Toronto using Light Rapid Transit.

3.3 Methodology

To address the research question of travel time differences the data are required to have a geographic component based on the mode of travel to represent our four variables. This would be followed by segmenting the O-D matrix for neighborhoods near transit stations. In order to achieve this task, an array of data management and Geographic Information System (GIS) methods were used to prepare data sets for analysis. A methodological arrangement of data prior to analysis was conducted in four phases (Figure 4).

Figure 4: Methodological Steps



3.3.1 O-D Travel Matrix Geographic Data

The census tract was the geographic unit in the study; hence the geographic file representing Canada's census tracts served as the cartographic boundary framework for mapping and spatial analysis (Statistics Canada, 2016a).

Originally portrayed in Lambert conformal conic projection (North American Datum of 1983), the re-projection was performed to reflect projected a coordinate system (NAD 1983 CSRS MTM, with optional Geographic Coordinate System of GCS North American 1983 CSRS) suitable for ideal topographic representation of Canadian cities in the research. Moreover, certain methods implemented in the study specifically required the use of a projected coordinate system (i.e. geometric road network buffers creation). All succeeding GIS operations carried out in the research utilized identical projected coordinate system.

In the first methodological step, a spatial join was performed between census tract boundary file (5,721), and O-D matrix travel files for all three cities (Figure 4). The join was two-tier. Initially, only origins were joined to census tract boundaries, followed by destinations join. Applying this method created two disparate geographic files, reflecting all trips that originated, and those that ended in the specific census tracts. The type of join performed was one-to-many combining non-geographic attribute O-D matrix trip data, to geographic census tract boundary layer, thus enabling thematic mapping and further analysis of aggregated results. Applying this approach kept the same composition and number of records of original O-D data, with an added geographic component.

3.3.2 Transit Systems

Geographic data representing rapid transit systems' lines and stations for three Canadian cites in the study were obtained in two ways: by either directly downloading it in geographic format from open data portals, upon their availability; or calculating it from scratch from General Transit Feed Specifications (GTFS) (Figure 4). GTFS is a common format for public transportation schedules and associated geographic information (Google, n.d.). It also known as GTFS static and it contains schedule, fare, and geographic transit information, and should be differentiated from the GTFS real-time component that contains arrival predictions, vehicle positions and service advisories (GTFS, n.d.-a). In our example GTFS static was the pertinent format to generate geographic files for transit routes and stops (GTFS, n.d.-b).

3.3.3 Geometric Network Walking Distance Buffers to Transit Stations

At this phase of the methodological procedure, *walking distance* buffers around transit stations were created for Toronto (Figure 5), Montreal (Figure 6) and Vancouver (Figure 7). The estimated spatial buffers will be adopted in the ensuing step to overlay and segment O-D data containing trip characteristics.

The decision on the exact sizes of the buffers were determined based on standards in transportation related academic literature, and commonly employed definitions utilized by transit agencies to define major transit areas and transit-oriented communities. The two buffers used in the study to delineate the service areas around public transit stations were: 400 and 800 metres (m). The prevailing standard in defining transit service area by walking distance to transit stops in academic literature has been 400 m (Gutiérrez & García-Palomares, 2008; Hsiao, Lu, Sterling, & Weatherford, 1997; Kimpel, Dueker & El-Geneidy, 2007; Murray & Wu, 2003; Neilson & Fowler, 1972; O'Neill, Ramsey & Chou, 1992; Zhao, Chow, Li, Ubaka & Gan, 2003).

The secondary walking distance buffer of 800 m was chosen due to its common adoption as service area to rail station (Kuby, Barranda & Upchurch, 2004; Schlossberg, Agrawal, Irvin & Bekkouche, 2007; Daniels & Mulley, 2013). Furthermore, a study of O-D Travel Survey in Montreal showed that service areas of 400 and 800 m captured most of the observed population concentration (El-Geneidy, Grimsrud, Wasfi, Tétreault & Surprenant-Legault, 2014).

Similarly, transit agencies are adopting identical terminologies and definitions. Vancouver's transit agency TransLink widely adopts measures of 400 m to frequent transit corridors and stations, and 800m to frequent transit stations, in its Transit-Oriented Communities Design Guidelines planning and analysis scenarios (Translink, 2012). More specifically the agency has the goal to support transit use and efficiency by focusing development within a 400–800 m (5–10 minute) walk from transit stations, and locate residential and business buildings, as well as facilities that generate large numbers of trips, in these transit accessible communities to help reduce the burden on the road network and support the use of sustainable modes for every day travel. Public transit travel times that are efficient, fast and comparable to car travel, would assuredly incentivize this agenda.

In like manner Toronto Transit Commission, in their planning reports, are regularly conducting and citing studies which use *major transit station* areas as delineated study areas. These are defined as the areas in and around any existing or planned higher-order transit (heavy or light rail) station within an approximate 500 to 800 metre radius representing about a 10-minute walk (Ministry of Municipal Affairs and Housing, 2019). The agency is noting the attempts to maximize the number of potential transit users that are within walking distance of the station.

As an example, the latest TTC report from 2019 indicates that approximately 88% of all residential development in the City is occurring within 500 metres of higher order transit (City of Toronto, 2019). The same report also adopts 800 m buffers in the predictive transportation planning analysis of one of the major proposed infrastructure projects in Canada, the Ontario Line, a 15.5-kilometre (higher-order) transit line with 15 stations to be built in the Toronto area. It further indicates that the Ontario Line will bring an additional 176,500 people within an 800-metre walk of higher-order transit that were not previously within walking distance of a rapid transit station before, and elaborates that the population currently living within an 800-metre walking distance of the proposed stations is projected to increase by 152,000 by 2041.

These examples illustrate the significance and commonalities in both academia and transit planning agencies in using identical and analogous buffers that influenced choices in our study.

Nevertheless, it is crucial to highlight that the walking distance buffers in the study were not circular or Euclidian buffers, commonly employed in planning studies conducted by transit agencies. Instead, geometric network buffers were applied as they portray and represent more realistic scenarios of walking distances from transit stations along the street network. Academic papers concurrently mention that Euclidian buffers overestimate the service area of the transit stations and suggest that use of geometric network buffers is preferred (El-Geneidy et al. 2014; Gutierrez and Garcia-Palomares 2008; Hsiao et al. 1997; Kimpel et al. 2007; O'Neill et al. 1992; Zhao et al. 2003).

Resultantly, the selected network buffers at 400 m and 800 m distances along roads around transit stations in Toronto, Montreal and Vancouver were calculated in GIS by overlaying it with a geographic file representing Canada's national road network (Statistics Canada, 2016b). This was done utilizing ArcGIS Network Analyst tools.

3.3.4 Segmenting O-D Trip Characteristics Matrix

GIS operations were further implemented to segment Origin-Destination travel data into six distinct study areas based on 400 m and 800 m network buffers for Toronto, Montreal and Vancouver (Figure 4). Segmentation was achieved with the *clipping* function, which extracted O-D input data containing all trip record features for specific cities by overlaying them with physical walking distance network buffer clip features. Alternatively, this task could and has been achieved for comparison purposes solely, by *intersection* function which is based on spatial join concept. The operation led to the creation of six origin - destination geographic subsets or sub-matrices based on walking distance buffers (Table 4) for each city in the study which were used as fundamental delineated areas for evaluation and interpretation of the results in the analysis section.

Table 4: Buffer Types based on Origin – Destination (O-D) Trip Scenarios

Buffer	Description
Origin and Destination within 400 m	Trips that originated and ended within 400 m of transit station
Origin and Destination within 800 m	Trips that originated and ended within 800 m of transit station
Origin within 400 m	Trips that originated within 400 m of transit station
Origin within 800 m	Trips that originated within 800 m of transit station
Destination within 400 m	Trips that ended within 400 m of transit station
Destination within 800 m	Trips that ended within 800 m of transit station

3.4 Geographic Information Systems for Transportation

Geographic Information Systems for Transportation, often referred by its acronym GIS-T, are the principles and applications of applying geographic information technologies to transportation (Rodrigue, Comtois & Slack, 2013). The four major components of a GIS (encoding, management, analysis and reporting) have specific considerations for transportation such as transportation network functional topology (nodes and links) associated with its spatial qualitative and quantitative data elements (direction, peak hour) that enables further analysis and modelling.

Rodrigue et al. (2013) and Hensher (2008) discuss many benefits of GIS-T however the one that is in the forefront and narrowly related to our research was the fact that various transportation specific data can be represented in GIS-T while carrying standard GIS functions (query, geocoding, buffer, overlay, etc.) to support data management, analysis and visualization needs.

This was specifically beneficial as our study implemented matrix data format while applying many standard GIS functions. According to H.L. Slavin (2008) and quoted by Hensher (2008) network analysis is perhaps the single most important function of a GIS-T. This entails the ability to represent network topology for the purpose of finding the shortest paths in terms of time and distance on a road network. This attribute was specifically valuable in spatially defining and creating transit-oriented neighbourhood layers in our study, which was the basis for all analysis.

3.5 Software

The software programs administered in the research, most notably in the methodological phases (Figure 4) and the analytical section were: RStudio, ArcGIS and TransCAD. All visual enhancements were done in Adobe Creative Studio.

RStudio, being the integrated development environment for R programming language, was employed for data management, manipulation, and statistical regression models.
ArcGIS Network Analyst tool assisted with creation of geometric network buffers, while ArcMap was optimal application for mapping and visualization purposes.

Lastly, TransCAD served as an ideal GIS-T (Geographic Information Systems for Transportation) platform for handling origin - destination (O-D) flow matrix travel data, something that has eluded traditional GIS software which have had non-adequate or limited capabilities in this area (Rodrigue et al. 2013). Hence the GIS analysis tools (Figure 4) implied in section *3.3.4 Segmenting O-D Trip Characteristics Matrix,* have been achieved in TransCAD, including the various spatial joins completed in prior methodological steps.

Both ArcMap and TransCAD were also implemented for various querying and visualizing scenarios. As such, they exemplified an enormous advantage cited by Anderson and Souleyrette (1996) that query tools make a GIS-T superior to non-GIS-based travel models, in that data for geographic subareas of networks or regions can be easily selected and modified. In our research those subareas were various trip scenarios based on trip origin and destination locations, consequently adopted in creation of travel time analytical maps.

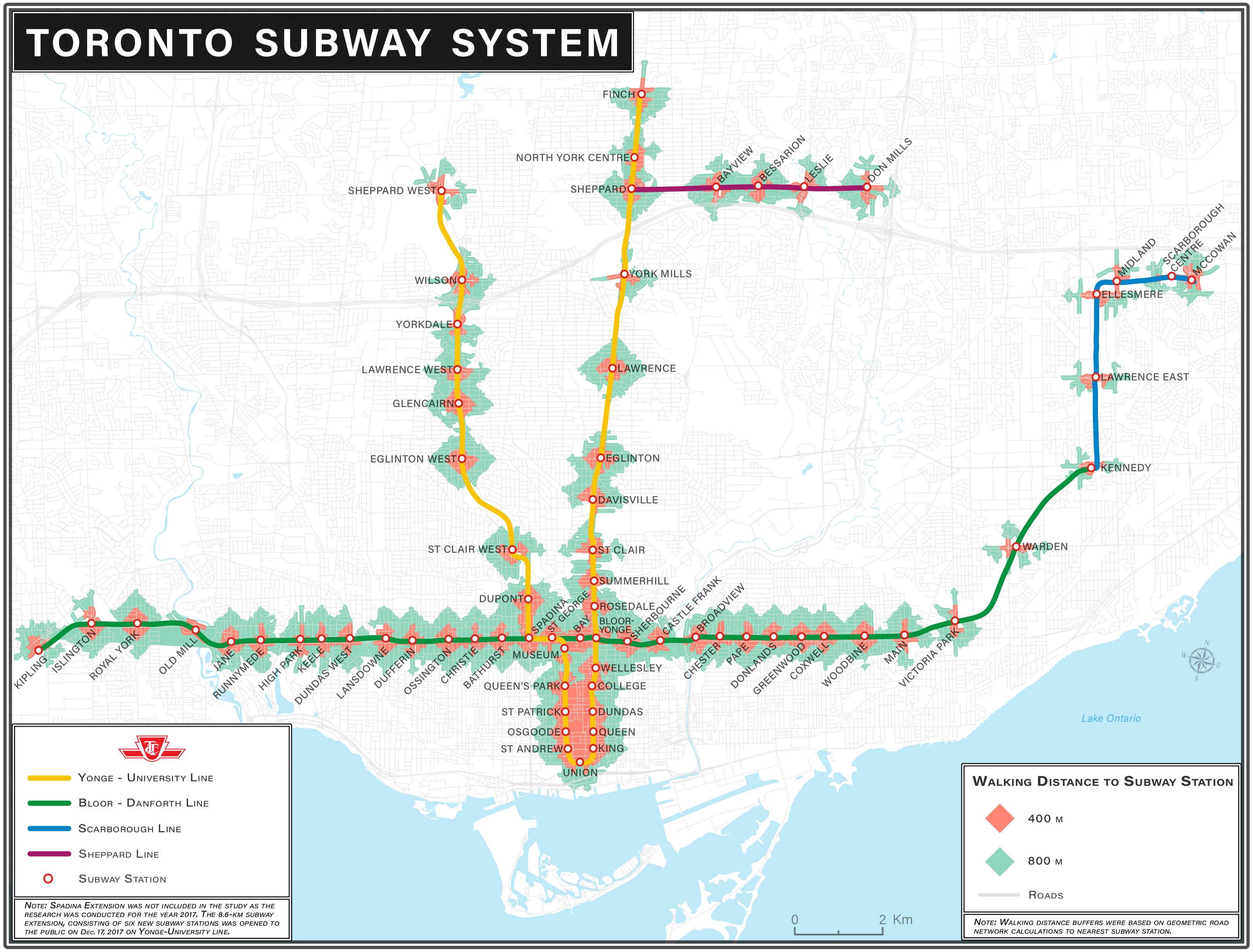


Figure 5: Toronto Subway System – Walking Distance to Subway Station

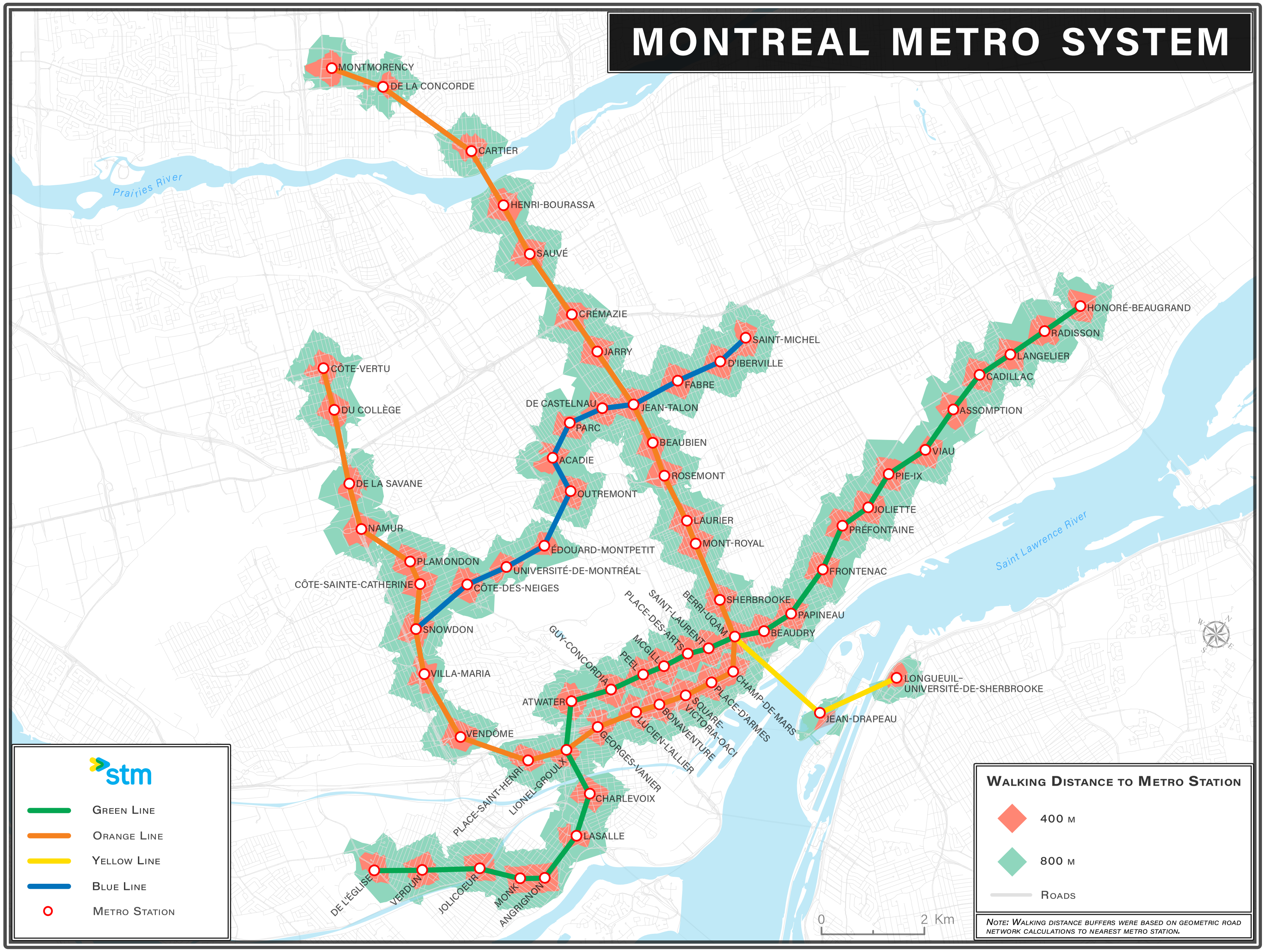


Figure 6: Montreal Metro System – Walking Distance to Metro Station

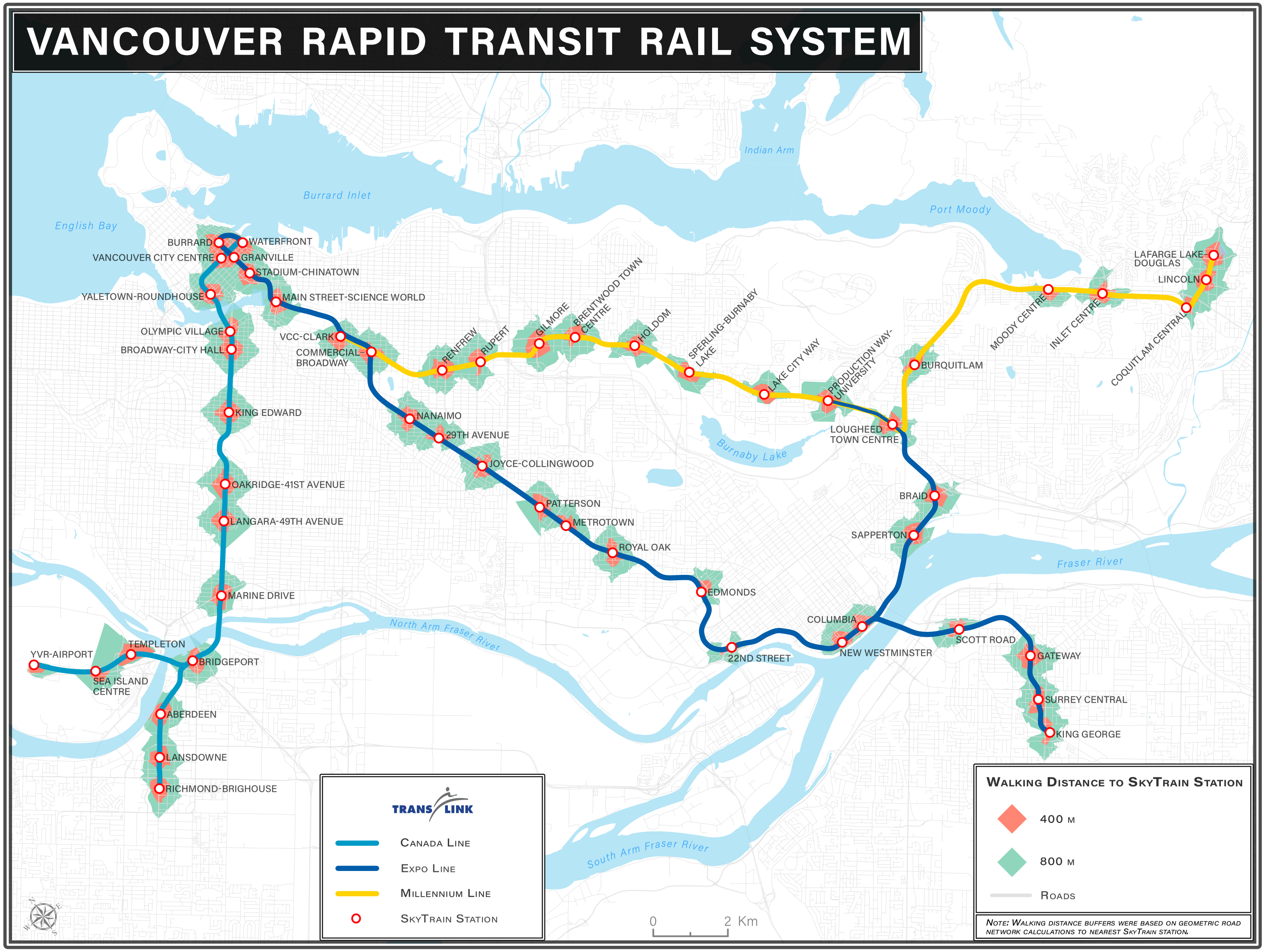


Figure 7: Vancouver Rapid Transit Rail System – Walking Distance to SkyTrain Station

CHAPTER 4 ANALYSIS

4.1 Description of Analytical Methods

All analyses were conducted by employing three approaches. First, descriptive statistics were computed for both vehicular and public transit modes for full sample data reflective of each study area; along with statistics relating to subsets of distinctly stratified buffer areas for six scenarios based on trip origins and destinations. Tables 5, 7 and 9 give summary of descriptive statistics for the variables used in the study: average travel time for public transit at peak hours, average travel time for car travel during peak and off-peak hours, and average road distance when travelling by car. Conclusions derived from the descriptive analysis provide an intuitive basis for the spatial and regression models in later analytical subsections.

Next, spatial analysis was performed by generating a set of thematic maps for three cities to display commute times by public transit and car travel (at peak hour) and highlight geographic trends, spatial distribution and visual travel mode comparisons. The basic geographic unit for the mapping was the census tract, and the measurement unit was average travel time in minutes. The geographic extent focused on centralized urban city regions where public transit infrastructure is located. In total, eight analytical maps were created for each study area.

However only four maps per city were directly reported for analytical purposes, while the other four were placed in the Appendix section for broader view. The analytical maps arranged in the analysis section are focusing on trips originating and ending within 400 metre census tracts from transit stations. In this manner more realistic travel time circumstances are portrayed. They are placed at the end of each *Spatial Analysis* subsections. Maps depicting scenarios of commuting within 800 metres (m) from a subway station were excluded due to the fair resemblance of information to 400 metre (m) buffer maps.

The supplementary maps (situated in appendix A section) display average travel times based on trips originating and trip destinations ending in census tracts for entire study CMAs. In those instances, travel times are largely inflated because trips are not limited by distance and are depicting commutes based for full CMAs.

In the real world most daily trips are shorter, and scenarios of using public transit to commute from disparate sections of our study regions are unlikely given the lack of currently available public transit infrastructure in remote CMA sections, thus making comparison to car travel not genuine. Nonetheless, these supplementary maps do indicate certain trends worth analyzing and contributing to the overall methodical evaluation of the results.

The third and last part of empirical analysis utilized the statistical technique of linear regression, which added value to our research by quantifying the magnitude of the relationships among the locational and travel time variables. It helped to answer the following questions:

- What are the differences between public transit and car travel times for trips that originate and/or end near transit stations?
- Will there be travel time differences, and by what margin, when the trips (in different iterations from and to transit oriented neighbourhoods) are differentiated by commuting distances?

The estimation of linear regression model is expressed as follows,

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_p x_p + \varepsilon \qquad \textbf{Equation 1}$$

where y is the dependent variable, and x_1 and x_2 are the explanatory variables. β_0 is the mean value, or conditional mean of y when both x_1 and x_2 are set to 0. The following entities in the equation show that β_1 relates to x_1 and it defines the relationship between x_1, which is an explanatory variable, and the dependent variable y, while controlling for another explanatory variable, x_2. ε is the error term, which accounts for the residuals or what is not explained by the regression model.

Dependent variables in our regression models were identical to the ones reflected in analytical maps, transit and car travel time during peak hours, with the additionally added dependent variable of car travel time during off-peak hours.

The independent, or explanatory, variables were the presence of census tracts in one of the following four scenarios: trips that are originating within 400 metres from transit stations, trips that are ending within 400 metres from transit stations, trips that are both originating and ending within 400 metres from transit station, and trips that are both starting and ending in 800 metre buffers from transit stations. In the regression models, the coefficients on the categorical explanatory variables are measuring change in travel time in minutes (continuous variable) based on a unit of change in explanatory variables, all else being equal.

Therefore, the aim of the regression was to estimate how different locational factors based on trip origins and destinations in areas around transit stations impact travel time based on specific mode choice. The models were estimated on data subsets segmented by trip lengths (less than 10.01, 15.01 and 20.01 kilometres) to represent realistic daily commuting distances. While the distance variable was originally calculated specifically for car travel on road networks, here it is used as a proxy for public transit trips as well. The reasoning behind that was that the road networks are shared for some public transit modes (buses and streetcars) while for train movements they are, based on visual observations (satellite imagery and aerial photography) and empirical perspective, highly analogous to road networks in three study areas.

Furthermore, whenever the buffers, vicinities, areas or neighbourhoods around transit stations are referred to in the analysis section, it should be implied at all times, that these refer to our basic geographic unit, a census tract, being fully or partially included in the buffers, as previously outlined in the methodological section.

4.2 Toronto Results

4.2.1 Toronto Study Area Descriptive Statistics

A breakdown of trip characteristics for the Toronto study area is presented in Table 5. First, let's observe statistics for trips that only originated, or ended, in buffers around subway stations. Average trip distances in the entire Toronto study area (consisting of Toronto, Hamilton and Oshawa CMAs) from origin buffers was 38 kilometres, while the trip lengths based on areas around subway stations as their destinations have reported similar results at 39 kilometres.

Table 5: Toronto O-D Trip Characteristics

	Transit Travel Time 8 am		Car Travel Time Peak Hours		Car Travel Time Off Peak Hours		Car Travel Distance (km)		Number of O-D Records	t-test*	p-value*
	Yes	No	Yes	No	Yes	No	Yes	No			
Origin and Destination within 400 m	43.33	131.7	43.89	68.0	22.40	40.8	12.81	52.41	29,929	3.7649	0.0001668
Origin and Destination within 800 m	45.61	132.6	44.52	68.3	22.60	41.0	13.34	52.82	51,076	-9.3235	2.2e-16
Origin within 400 m	95.70	135.16	61.39	68.56	35.75	41.23	38.20	53.71	246,698	-271.63	2.2e-16
Origin within 800 m	96.66	136.73	61.45	68.87	35.62	41.50	38.30	54.37	322,276	-318.34	2.2e-16
Destination within 400 m	98.51	134.78	78.79	66.16	36.69	41.10	39.22	53.57	246,698	-137.7	2.2e-16
Destination within 800 m	99.33	136.22	78.19	65.72	36.57	41.32	39.34	54.18	322,276	-168.69	2.2e-16

Note: Transit Travel and Car Travel times are based on average travel times expressed in minutes. Number of O-D records shows number of records within buffers. Note: T-test values reported here (and the associated p-values) are for comparison of average travel times by public transit and by car that originated and terminated in census tracts within 400 m from subway station. Note*: all other comparisons were also statistically significant and were not reported here.*

Overall, the trip characteristics values exposed significant average differences between the trips subsumed in one of the buffers and those that are outside, in nearly all variables and scenarios. For instance, in origin-based trip scenarios, travel times for trips outside of the buffers are reporting 41 % higher values for transit and 12 % for car during peak hours, and 15 - 17% for car when there is no congestion. The travel time differences are similar for observations based on trip destinations where they reported 37 % longer commutes for transit, and 12 -13 % for off-peak vehicle commutes. There was one notable exception in the entire study sample for Toronto where travel times associated with our transit-oriented neighbourhoods were longer than the subset of trips outside of the buffers. That was the instance of peak hour vehicle travel times that ended in 400 and 800 m buffers around subway stations in Toronto, where commutes were 19 % longer.

This is potentially due to congestion on roads around transit stations contributing to longer commutes. Interestingly, this trend is not evidenced when trips are originating in the areas around the stations. In another instance of highlighting differences in and outside of buffer zones, origin and destination scenarios (traveling from and to areas around subway stations) revealed that trips which were entirely outside of buffer zones reported over 191 % higher times for public transit, above 53 % for peak-hour car travel, 81 % and higher for car travel without congestion, and over 296 % in average distances traveled by car. It should be noted that identical trends are observed in Montreal (Table 7) and Vancouver (Table 9) study regions when comparing variables associated with transit-oriented vicinities, and those that were not. It leads to the conclusion that trips contained in one of the buffer scenarios almost exclusively exhibited shorter commutes and distances traveled.

As alluded to in the introductory part of the analysis section, the most realistic scenario, and that which is the narrower focus of our research, are trips that are starting and ending within neighbourhoods around the subway stations. To begin with, the average distance of these trips in Toronto when travelled by car is much smaller at 13 kilometres, which closely reflects more reasonable daily distances for most urban commuters for both modes of travel. Public transit travel times calculated for peak hours at 8 am for these trips are 43 minutes and 46 minutes, for 400 m and 800 m buffers respectively. When public transit travel times are contrasted with car travel during peak hours, they are revealing comparable commutes at 44 and 45 minutes. These figures align with reported national commuting averages.

Additionally, there is an argument in transportation planning which states that the maximum desirable commute throughout human history, regardless of transportation technology, has remained at forty-five minutes (Garreau ,1992).

The question this begets, after conveying nearly indistinguishable travel time values for public transit and car (at 8 am) when commuting from and to transit oriented communities around subway stations, is would commuters still prefer public transit if commute times are just comparable and not more favorable than those made by car. What's more, public transit commuters traveling from or to locations outside of the transit-oriented neighbourhoods would experience greatly exacerbated commutes due to additional times to get to the subway station or due to using slower public transit modes.

Each travel mode, in addition to travel time characteristics, also has other benefits and choice determinants, such as travel cost, availability of service and comfort to only name a few. These are beyond the scope of this study. However, in the next subsection geographic trends are analyzed to complement our findings from descriptive statistics section and further observe potential locational differences and benefits in the City of Toronto region between public transit and car travel times.

4.2.2 Toronto Spatial Analysis

Spatial analysis was conducted with a series of thematic maps depicting categorical travel time classes. Most frequently, six distinct categories were used by manually adjusted breaking points, for better visual comprehension. Cartographic elements relating to transportation infrastructure, which were used in GIS operations in the methodological section, were presented in all analytical maps. For Toronto, transportation infrastructure was represented by 4 subway lines, 69 subway stations and the local road network (Figures 8 to 11).

In one of the most optimal transit oriented scenarios portraying census tracts for trips originating and ending within 400 m from subway stations (shown in Figure 8), average public transit commutes were most efficient for areas in the Central Business District (CBD) characterized by subway stations on the southern portion of the Yonge – University line. More particularly areas in the financial district spreading around Union station eastward to Queen station, and from Union station westward to Osgoode, are exhibiting shortest average public transit commutes under 35 minutes. The additional zones with identically efficient public transit scenarios were the ones around or close to inter-connecting subway stations between two major Toronto subway lines: Yonge – University and Bloor – Danforth. Additional census tract cluster displaying equivalently favorable public transit commutes, that is outside of previously referred concentrated zones associated with downtown, is the locality around Broadview station in the eastern borough called East York on the Bloor-Danforth line. The trend is gradually dissipating outwardly from downtown areas almost uniformly, first to public transit travel time zones in the 35.01-40 minute category, followed by the 40.01-45 minute class, and continuing to slowest commutes in the area on the outskirts of the City of Toronto.

Neighbourhoods at the most outward ends of all subway lines are somewhat expectantly represented with the slowest public transit commutes. Following the same logic, Scarborough and Sheppard lines, being situated on the eastern and northern peripheries of urban Toronto bordering with suburban communities, are revealing these results as well, more particularly with public transit commutes ranging from 50.01 – 55 minutes, and over 55 minutes. The public transit times at peak hour described in previous examples (Figure 8) are based on average census tracts calculations for trips originating in these zones.

Evaluating the same public transit scenario for journeys originating and ending in 400 m from subway stations but changing the average trip calculation based on trip destinations (Figure 9), nearly identical geographic distribution is noted, with very few minor differences. These minimal contrasts revealed up to 5-minute average commuting differences in a negligible number of census tracts in downtown and around stations on Scarborough and Sheppard subway lines.

In the next part of the spatial analysis, peak-hour car travel times (based on trip origins) when travelling from and to neighbourhoods around subway stations (Figure 10), were observed. Corresponding geographic distribution is exposed as for public transit, with shorter commutes clustering in the downtown core and progressively increasing towards neighbourhoods at the end of subway lines. A notable difference is the increased number of census tracts in the central city area spreading around midtown, with shorter average commute times in the under 35-minute category. Similarly, shorter commutes were present in census tracts in the northern part of the city around Yorkdale and York Mills stations, presumably due to the immediate accessibility to a highway. A few census tracts around Jane station on the western portion of the Bloor – Danforth line showed better travel times by car as well, again access to few surrounding highway routes might have been one of the explanations.

On the other hand, dissimilar spatial dispersal was revealed, in contrast with the previous three scenarios, for vehicle travel when it is based on trip destinations (Figure 11). Distribution is different in two ways: census tracts in financial districts are experiencing quite longer commutes (45.01-50 minutes); and there are more frequent occurrences of census tracts in the overall system with generally shorter commutes (35.01-40, 40.01-45 minutes).

Supplementary maps based on calculations for the full study area, depicted shortest public transit commutes around subway stations, with regionally best scenarios being when trips are based on origins (Figure A-1). In comparison, transit commutes were elongated for the north east part of the city when average travel times are based on trip destinations (Figure A-2) for the entire region. Another noteworthy observation is that car travel times are expectedly and considerably shorter overall in comparison to public transit trips regardless if calculations were based on origins (Figure A-3) or destinations (Figure A-4). In both, vehicular travel trip scenarios fastest travel times were depicted in large clusters in the northern part of the city close to highways.

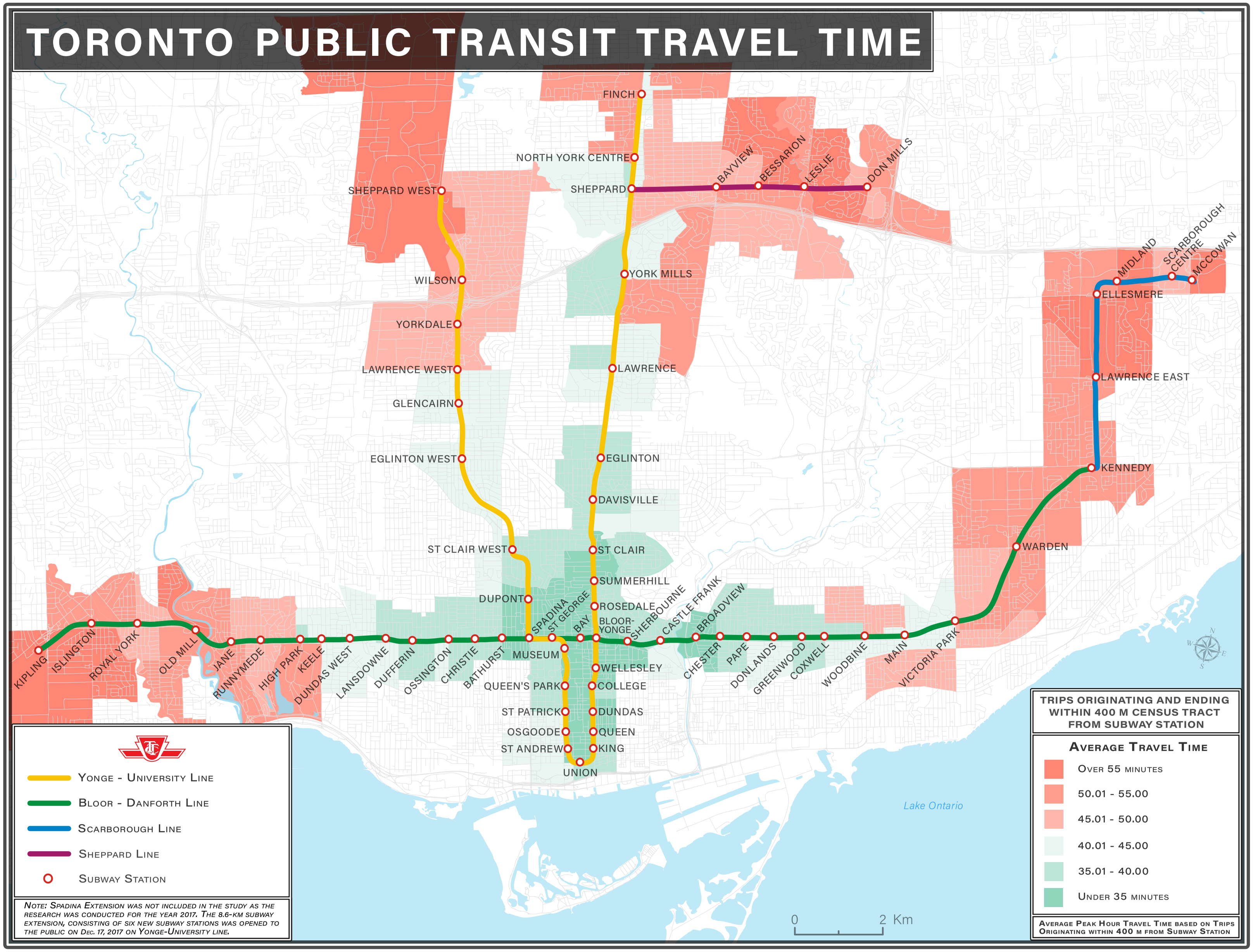


Figure 8: Toronto Public Transit Travel Time – Trips Originating and Ending within 400 metre Census Tract from Subway Station (based on trip origins)

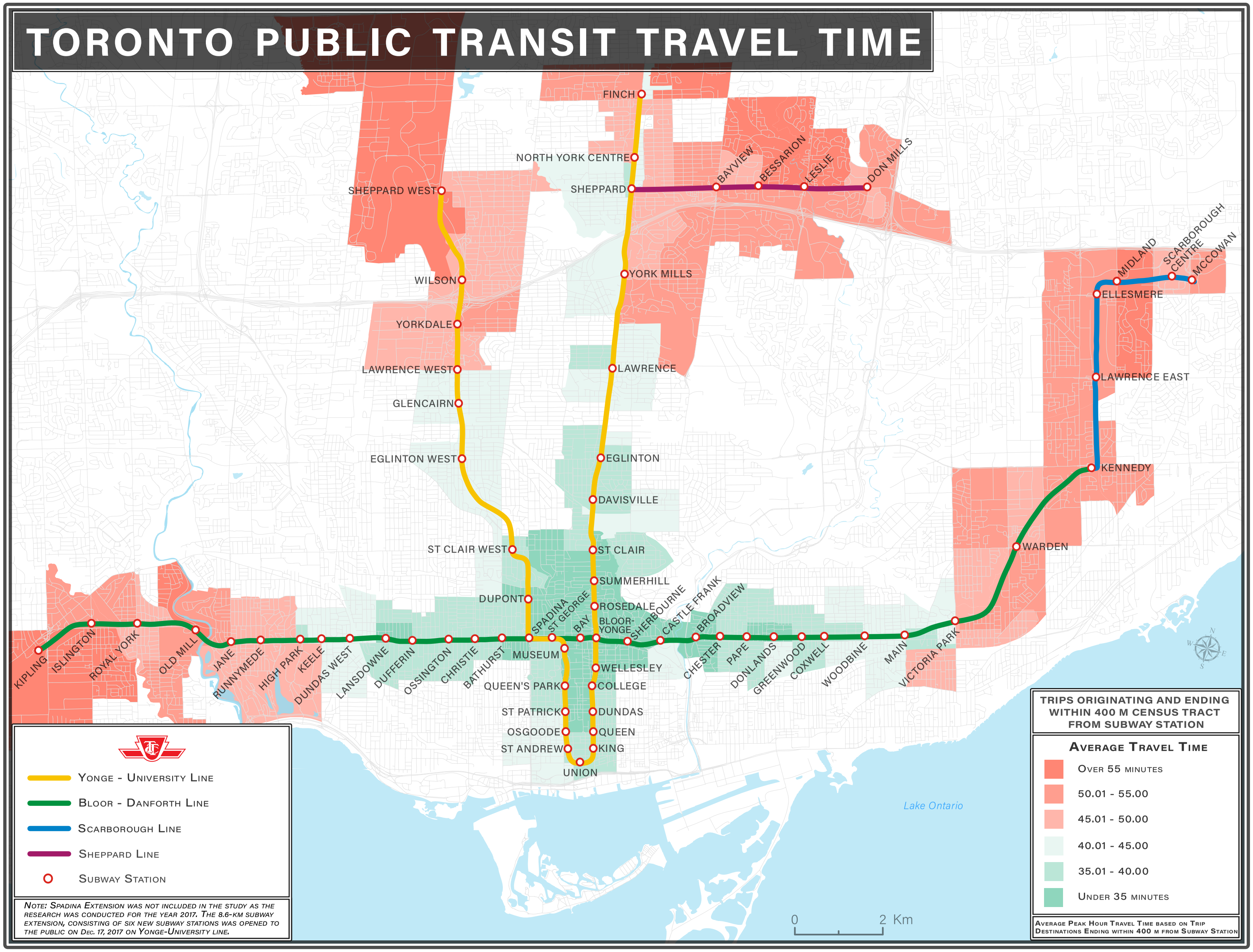


Figure 9: Toronto Public Transit Travel Time – Trips Originating and Ending within 400 metre Census Tract from Subway Station (based on trip destinations)

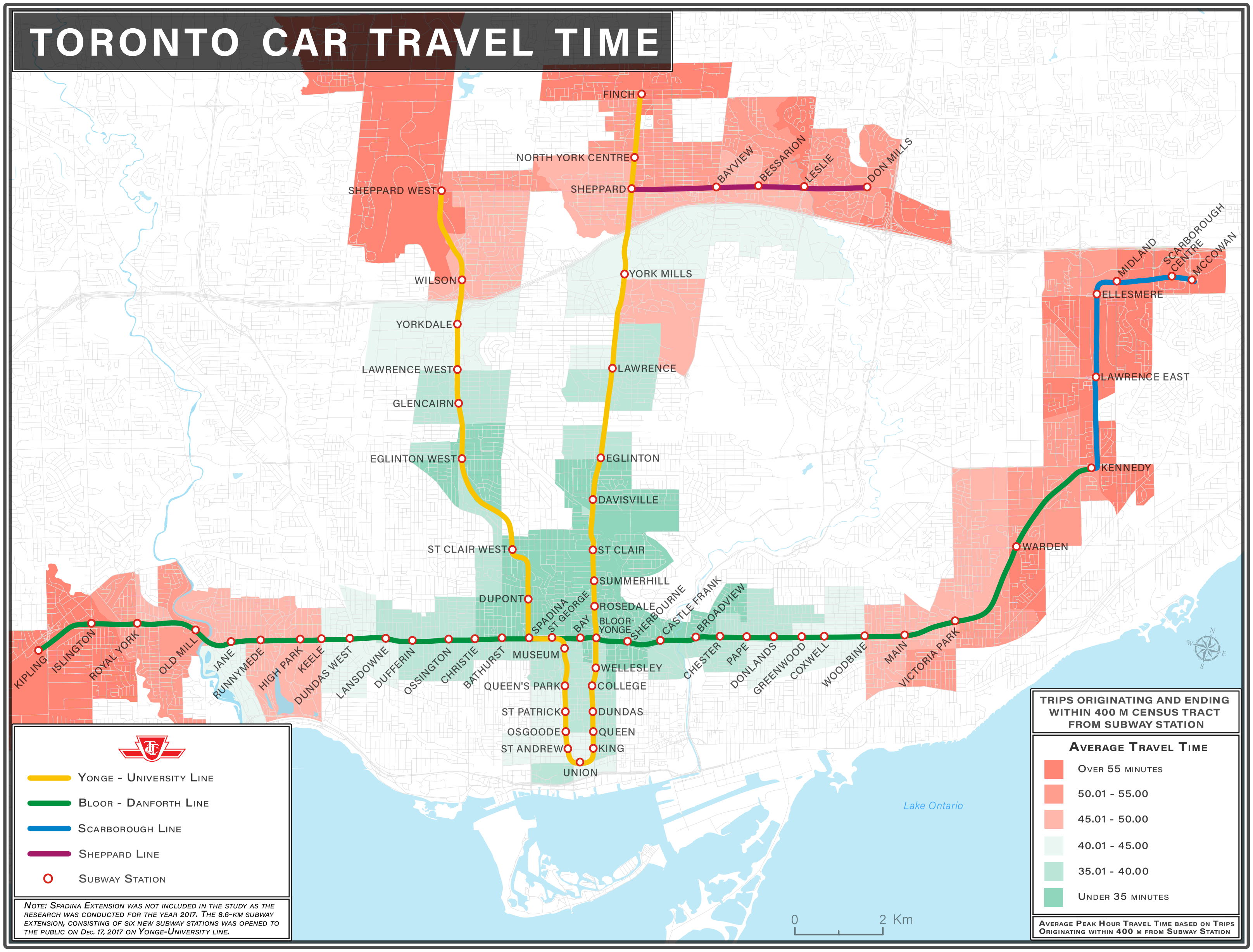


Figure 10: Toronto Car Travel Time – Trips Originating and Ending within 400 metre Census Tract from Subway Station (based on trip origins)

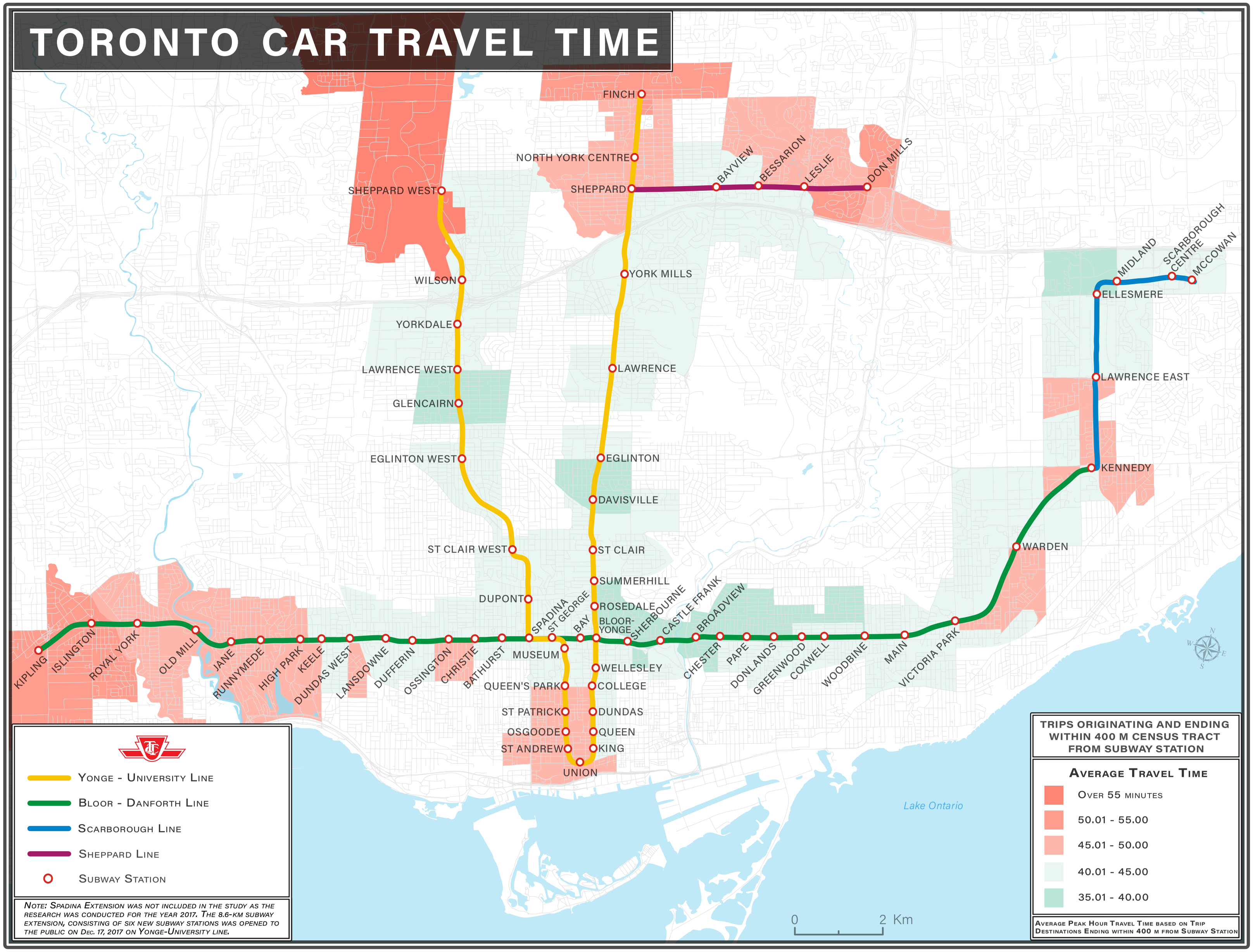


Figure 11: Toronto Car Travel Time – Trips Originating and Ending within 400 metre Census Tract from Subway Station (based on trip destinations)

4.2.3 Toronto Regression Models

Detailed regression results are presented in Appendix B. For Toronto (Tables B-1 to B-9), as for the other two metropolitan regions in the study, nine regression models were developed in total. They were established on different scenarios based on apportioning datasets by various commuting distances (trips less than 10.01, 15.01 and 15.01 kilometres). Estimates were generated for three specific transit mode arrangements (public transit, car travel during peak-hour, car travel during off-peak hour) by regressing transit travel time on the categorical locational variables, which were the presence of census tracts in one of our origin and destination trip scenarios.

The coefficients from the models and their significance levels are summarized in Table 6. In the presence of other explanatory variables, the reported coefficients are conditional upon other factors in the model being held constant. Models were tested for and showed no presence of heteroskedasticity, a condition where variance is not constant, by obtaining regression outputs in RStudio which listed F Statistic and its associated significance values (Appendix A). Results revealed that all estimated coefficients relating to trips associated with transit-oriented neighbourhoods in Toronto exhibited high statistical significance at 99 % level in explaining transit travel times.

Table 6: Summary of Regression Coefficients for Toronto

	Public Transit			**Car Travel – Peak Hour**			**Car Travel – Off Peak Hour**		
	(Dependent Variable - Travel time in Minutes)								
	Trip Distance								
	< 10.01 km	< 15.01 km	< 20.01 km	< 10.01 km	< 15.01 km	< 20.01 km	< 10.01 km	< 15.01 km	< 20.01 km
Origin 400m	-5.892***	-8.114***	-10.646***	4.591***	5.502***	5.480***	2.488***	2.772***	2.619***
Destination 400m	-5.516***	-7.434***	-9.641***	5.933***	8.119***	10.036***	2.485***	2.826***	2.928***
Origin/Destination 400m	-9.558***	-12.280***	-16.050***	3.646***	5.012***	4.788***	1.647***	1.911***	1.512***
Origin/Destination 800m	-8.446***	-11.394***	-15.133***	3.964***	5.081***	4.917***	1.817***	1.997***	1.553***

*Note [1]: Asterisks (***) beside regression coefficients refer to significance values at the following levels: *p<0.1; **p<0.05; ***p<0.01.*

In the first commuting distance circumstance for trips shorter than 10.01 kilometres, several locational variables demonstrated quite favorable public transit times for trips originating and ending in census tracts within 400 and 800 metres from subway stations.

These trips were, all else being equal, reciprocally 9.6 and 8.4 minutes shorter, than all other public transit 10-kilometre trips in the region. Additionally, even commutes that only originated, or ended, within 400 m from the stations, when delineated by the 10.01-kilometre commuting distance, showed average travel time savings of 5.9 and 5.5 minutes respectively. All the mentioned scenarios confidently explained between 34% and 61 % variance in travel times (Table B-1).

These outcomes are not surprising considering that commutes from and to the areas around transit stations will give an average traveler benefit of using subway trains, which is the fastest public transportation mode, but also one that provides the added advantage of having easy and fast access to the subway stations, which additionally serve as hubs for other public transit modes (buses or streetcars). Regardless of the intuitive outcomes in this model, these initial results contribute to the on-going debate that living and commuting from and to transit-oriented neighbourhoods will have significant beneficial travel times when overall public transit commutes are compared in urban metropolitan regions.

In the identical scenario for trips constituting a 10-kilometre maximum travel distance, car travel times during peak hour were somewhat longer for trips associated with neighbourhoods around subway stations, than the overall 10-kilometre peak hour vehicle trips in Toronto study area. The average travel times were longer ranging from 3.6 minutes for those commuters going from and to destinations within 400 metre transit stations buffers, to 5.9 minutes for the commuters traveling from various city parts but whose trips ended in the same buffers. The latter also explained 58 % variance of the trips (Table B-2). The fact that trips associated with areas around subway stations are longer for car commutes when compared to the remainder of the region might be the result of increased density and congestion frequently associated with transit-oriented neighbourhoods. However even when not considering for congestion, which in large cities contributes enormously to average commutes, car trips were repeatedly longer than those in the research area, even though to a lesser degree and with minimal travel times differences. More specifically these trips were 2.4 minutes longer for trips originating, equally longer for trips ending (also explaining 39 % of variance in these trips; Table B-3), and 1.6 to 1.8 minutes longer for trips both originating and ending near the subway stations depending on the proximity to them.

An intriguing observation in the prior models is noticed when comparing constants along with coefficients (Tables B-1, B-2 and B-3). As indicated apropos of regression equation (Equation 1) β_0 is the mean value, or conditional mean of y when both x_1 and x_2 are set to 0. When we apply coefficients and constant values to the equation the results for peak-hour 10-km commutes reveal results of 29.3 minutes for public transit and 25.4 minutes for car commutes in the most flattering and complimentary scenario in favour of public transit agenda, which is commuting from and to the areas in the 400 metre walking distance buffers from subway stations. These public transit statistics for 10-kilometre trips are showing respectable and advantageous values, particularly when compared to average travel times of 43.3 minutes for the whole system (Table 5). Nevertheless, even in this most favorable commute scenario they are longer by 15 % than car travel, all else being equal. Even more so when commuting from and to larger areas around subway stations, defined by 800 metre walking distance buffers, differences are more pronounced with public transit trips being 21 % longer. These showings are relatively counter intuitive as the expectation would rest on public transit trips to demonstrate either highly comparable or superior travel times during rush hour.

Trends and directions of associations were equivalent among locational and commute time variables when trip lengths are limited to 15 kilometres (Table 6; Tables B-4, B-5 and B-6). Results, when contrasted to the entire study region, showed exaggerated travel time values for each transport mode. For example, public transit commutes were 12.3 and 11.4 minutes shorter when traveling from and to 400 and 800 metre buffers respectively, than the same distance trips in the rest of the region. Increased time savings were also exhibited for commuters solely traveling from 400 metre buffers to the rest of the study area by 8.1 minutes; or traveling to the buffer zones from the other parts of the region, by 7.4 minutes. Variances in the previous instances confidently explained travel times at 45 % and 60 % in the first example set, and 44 % and 37 % in the following one, listed in the same order (Table B-4). On the other hand, the increased trip distance scenario of 15-minute, amplified vehicle travel times during peak hours by 5 minutes, when originating and ending travel in transit-oriented neighbourhoods, in comparison to the overall 15-kilometre vehicle trips in Toronto, Hamilton and Oshawa CMAs, which constitute our study area. Trips only starting in 400 metre buffers were 5.5 minutes longer, and those ending in them were 8.1 minutes longer. Yet again, congestion which leads to slower traveling speed at increased distances, is most likely the contributing factor.

This fact, based on the variables in our study, can also be detected by negligible vehicle travel differences during off peak hours which ranged from 1.9 to 2.8 minutes in four scenarios for 15-kilometre trips. Revisiting the more defined aspect of our hypothesis, comparing average public transit to car travel times, all else being equal, transit commuters traveling up to 15 kilometres will experience 3 % and 8 % longer travel time when commuting from and to census tracts within 400 and 800 m walking distance buffers from subway stations, respectively. Increased trip (from 10 to 15 kilometres) distance is therefore indicative of the narrower comparability between public transportation and vehicular travel.

In the final commuting distance circumstance in our regression models, which focuses on trips with maximum commuting distance of 20 kilometres (Table 6; Tables B-7, B-8 and B-9), public transit times were at best 16.1 and 15.1 minutes shorter than the equal length transit trips in the rest of the region. These reflect commutes between areas around Toronto subway stations as defined by 400 and 800 m buffers, respectively. The locational factors each explained significantly 43 % and 60 % of the variance in the public transit times (Table B-7). These more prominent time savings can be contributed to larger sample size when trips are subset at 20 kilometres, indicating that longer trips will maximize travel time values in urban and highly inter connected urban Toronto area, in comparison to notoriously slower public transportation options in the rest of the region which rely mostly on buses. Regression coefficients for peak hour vehicular travel, were to a degree similar between trips delimited by 15 and 20-kilometre length. However, the latter exhibited lower variance results in explaining car travel times (Table B-8), in most independent variables, except trips whose destination ends in 400 m buffers around subway stations, which explained 61 % of variance in travel time. On the other hand, vehicular trips during off peak hour (Table B-9) showed nearly equal coefficients and variance levels as those in 15-kilometre scenario (Table B-6).

Assigning coefficients and constants from the regression models to the equation shows that, all else being equal, average peak hour travel times for public transit 20-kilometre trips are 38.9 and 40.5 minutes for commutes between transit-oriented neighbourhoods as delimited by our 400 and 800 metre buffers respectively. Transit commutes were discretely 1 % shorter, and 3 % longer for each scenario, respectively, than vehicle travel times, concluding that the model with the longest trips in our research produces nearly identical values during the peak hour commutes.

4.3 *Montreal Results*

4.3.1 Montreal Study Area Descriptive Statistics

Descriptive trip characteristics for the Montreal study region are presented in Table 7. Shorter commute times are reported across all categories when compared to those for Toronto. Trips that are solely originating in buffer zones are showing average commute times of 76 and 78 minutes for transit (400 m and 800 m buffers), 44 minutes for car travel during peak hour and 28 minutes for off-peak time. Values for census tract destination buffers were disclosing alike characteristics as previous examples except for vehicle commute times during peak-hour which were 52 minutes in both destination buffer categories. It should be specified that shorter commutes for origin (400m, 800m) and destination (400m, 800m) scenarios in Montreal were determined based on calculations for the entire study region which was almost half the size of Toronto (Table 1). Smaller region in the above samples is evidenced in shorter average distances traveled by car which were 22 kilometres in Montreal, versus 38 to 39 kilometres in Toronto in the same circumstances. Since distances are directly correlated to travel times, these were plausibly shorter in contrast to Toronto as well.

Table 7: Montreal O-D Trip Characteristics

	Transit Travel Time 8 am		Car Travel Time Peak Hours		Car Travel Time Off Peak Hours		Car Travel Distance (km)		Number of O-D Records
	Yes	No	Yes	No	Yes	No	Yes	No	
Origin and Destination within 400 m	31.75	118.61	32.60	54.33	18.75	33.18	8.80	32.44	40,804
Origin and Destination within 800 m	35.03	122.10	33.47	55.19	19.17	33.77	9.33	33.42	78,400
Origin within 400 m	75.97	125.07	43.51	55.98	27.60	33.85	22.00	33.88	195,940
Origin within 800 m	77.55	129.98	43.63	57.34	27.62	34.55	22.12	35.18	271,600
Destination within 400 m	75.38	125.23	52.07	53.73	27.71	33.83	21.80	33.94	195,940
Destination within 800 m	76.88	130.25	51.95	53.97	27.75	34.50	21.95	35.25	271,600

Note: Transit Travel and Car Travel times are based on average travel times expressed in minutes. Number of O-D records shows number of records within buffers.

Nonetheless, due to reasons previously stated, the more definitive focus is to be placed on trips in the first two columns showing statistics for trips originating and ending in neighbourhoods around metro stations. The average distance, as measured by vehicular travel, was 9 kilometres, while the average off-peak car travel time was 19 minutes. Direct comparison in the most ideal commuting circumstance, journeys from and to 400 metre buffers, at peak hours showed almost identical average commutes by public transit and car at around 32 minutes, with transit travel time being longer by 5 % in larger buffers.

Assessing and relating the results for the urban Montreal region to that of Toronto, it can be concluded that exacting trends are occurring for transit-oriented neighbourhoods in that transit and car commutes are precisely or virtually identical, depending on the exact distance to a transit station. Another interesting fact emerging from our descriptive tables was that, a Montreal commuter (Table 7), in contrast to one in Toronto (Table 5), who travels from and to the areas in the immediate vicinity around transit stations (classified by 400m buffers), spends on average 27 % less time commuting by public transit in the morning, 26 % less time commuting by car in the rush hour, 16 % less time commuting by car when there is no congestion, and also travels 31 % less distance. Similarly, if the commutes are from and to somewhat extended distances from metro or subway stations (classified by 800m buffers), commuter in Montreal still travels 23 % less by public transit and 25 % by car during rush hour, 15 % by car during off-peak hours, with 30 % shorter traveled distances by car, than the daily commuter in Toronto.

4.3.2 Montreal Spatial Analysis

As stated beforehand in various parts of the study, Montreal is a city with high levels of public transit usage, and shortest overall average public transit travel times when commuting between the areas around metro stations.

Evaluating public transit commutes further with an added geographic component (based on trip origins), and juxtaposing it with Toronto (Figure 8), increased the number of census tracts in the immediate vicinity of metro stations with superior commute value categories (under 25 minutes, 25.01-30 minutes) as shown in the map (Figure 12) across the Montreal area on all 4 metro lines. There are a few exceptions to this, at the end of the Orange line ending in Laval, across Prairies River, and includes areas around three metro stations (Montmorency, De La Concorde and Cartier); and metro stations on both ends of the Green line.

Due to the higher number of neighbourhoods with enhanced public commute time values, the initial conclusion is that almost regardless of where one lives or commutes to in Montreal, as long as it is in the neighbourhoods in the metro station locales, those commutes will be fast, efficient and favourable (based on trips originating and ending in 400 metre buffers around metro stations).

Based on the same scenario, equivalent spatial distribution is present when average transit commute times are calculated based on trip destinations (Figure 13). Several neighbourhoods that experienced less favorable commutes are located around the mid section of the Blue line (Édouard-Montpetit and Acadie stations), and the north-western section of the Orange line (Plamondon to Côte-Vertu stations).

Contrasting the previous two transit scenarios with that of vehicle travel, a somewhat similar dispersal of census tracts across the City of Montreal is observed. Figure 14, which shows average car travel times between transit-oriented neighbourhoods based on estimation when travelling from census tracts of origin, reveals an even more pronounced number of neighbourhoods with lowest commute categories concentrated in the central-city section. Most of the neighbourhood districts in this scenario are depicted in 25.01 – 30 minute category, while the main improvements in travel times are noticed in the western section of the central city between Green and Blue metro lines, and in the north-western section of the Orange line. In both examples travel time savings over public transit were 15 to 20 minutes, and over. Additional remarks should be noted for zones at the end of Metro lines (Green line, and portion of the Orange line in Laval). While they experienced the highest public transit commutes in the city in the preceding scenarios, car travel times in these zones were even longer by 5 to 10 minutes and often portrayed in the over 45-minute commute category.

Upon adjusting average travel time calculation based on trip destinations (Figure 15) advantageous vehicle commutes are still present in central city region. Trips were considerably lengthier in two city sections. In the north western part of Montreal, represented by a portion of the Orange metro line (from Côte-Sainte-Catherine to Côte-Vertu stations), especially pronounced differences were revealed in commutes based on destinations. In a few neighbourhoods around De La Savane and Du Collège metro stations these were up to 15 to 20 minutes longer, than car travel times for the same neighbourhoods when trip calculations were based on origins. Related variations exist in the western portion of the Blue metro line (vicinities around Université-de-Montréal and Côte-des-Neiges stations) where the destination-based car commutes were 5 to 10 minutes longer. Conversely, areas around metro stations in Laval and the eastern ending section of the Green line are experiencing 5 to 10 minute shorter trips when comparing vehicle trips based on trip destinations to those constructed on trip origins.

Auxiliary maps were generated based on computations of average travel times for the entire Montreal study area. While the commutes are massively magnified since they are not constrained by distance, several valuable themes can be detected. Firstly, public transit commutes, irrespective whether the calculations were based on trip origins (Figure A-5) or trip destinations (Figure A-6) are exhibiting the shortest values in the neighbourhoods around all metro stations. Secondly, car commutes are considerably faster than public transit.

Comparing car trips for the full area, those based on origins (Figure A-7) are considerably slower in the eastern part, and incrementally faster in the western part of the city. Car trips based on destination estimates are showing the lowest values in the central city section (Figure A-8).

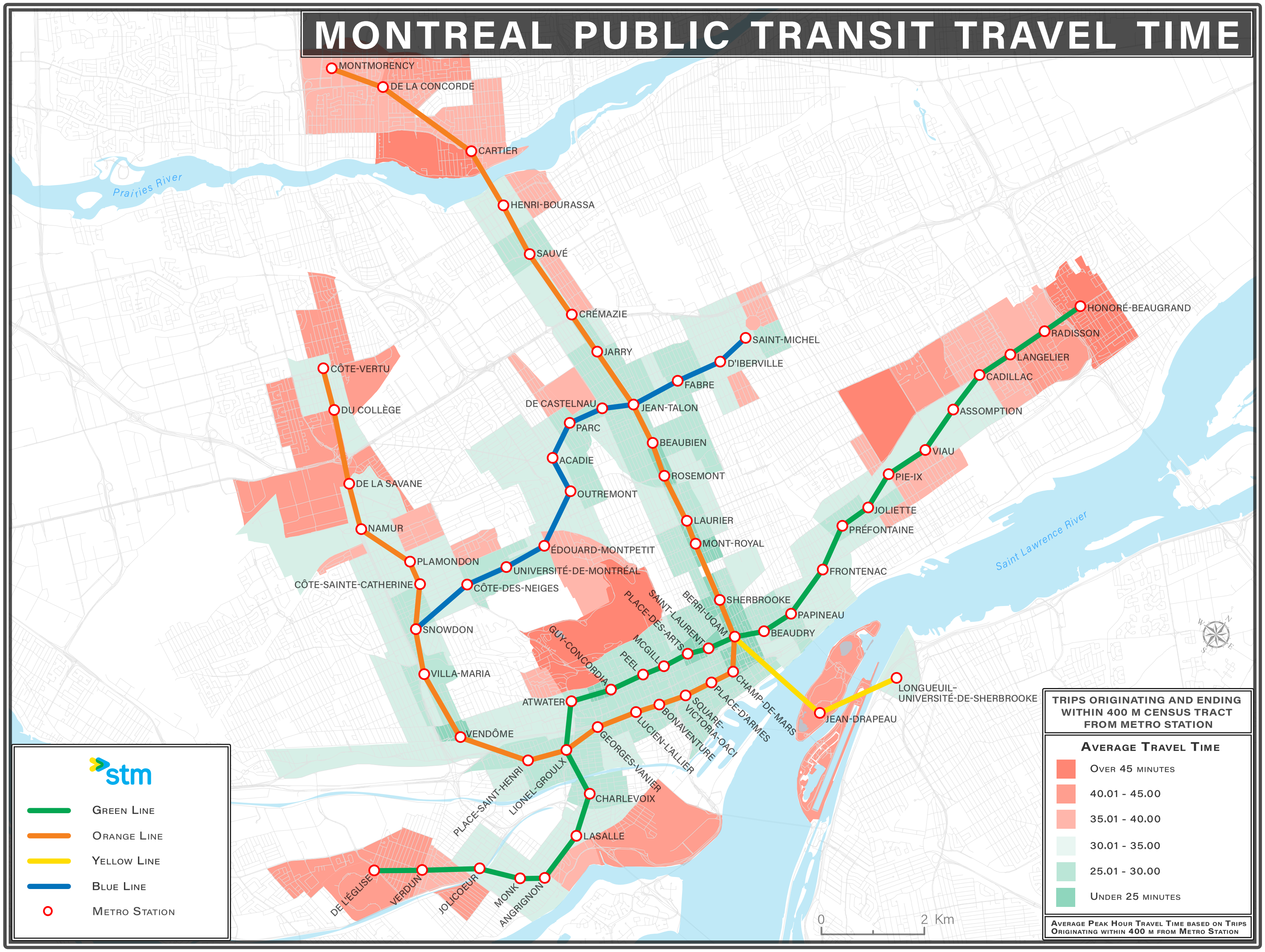


Figure 12: Montreal Public Transit Travel Time – Trips Originating and Ending within 400 metre Census Tract from Metro Station (based on trip origins)

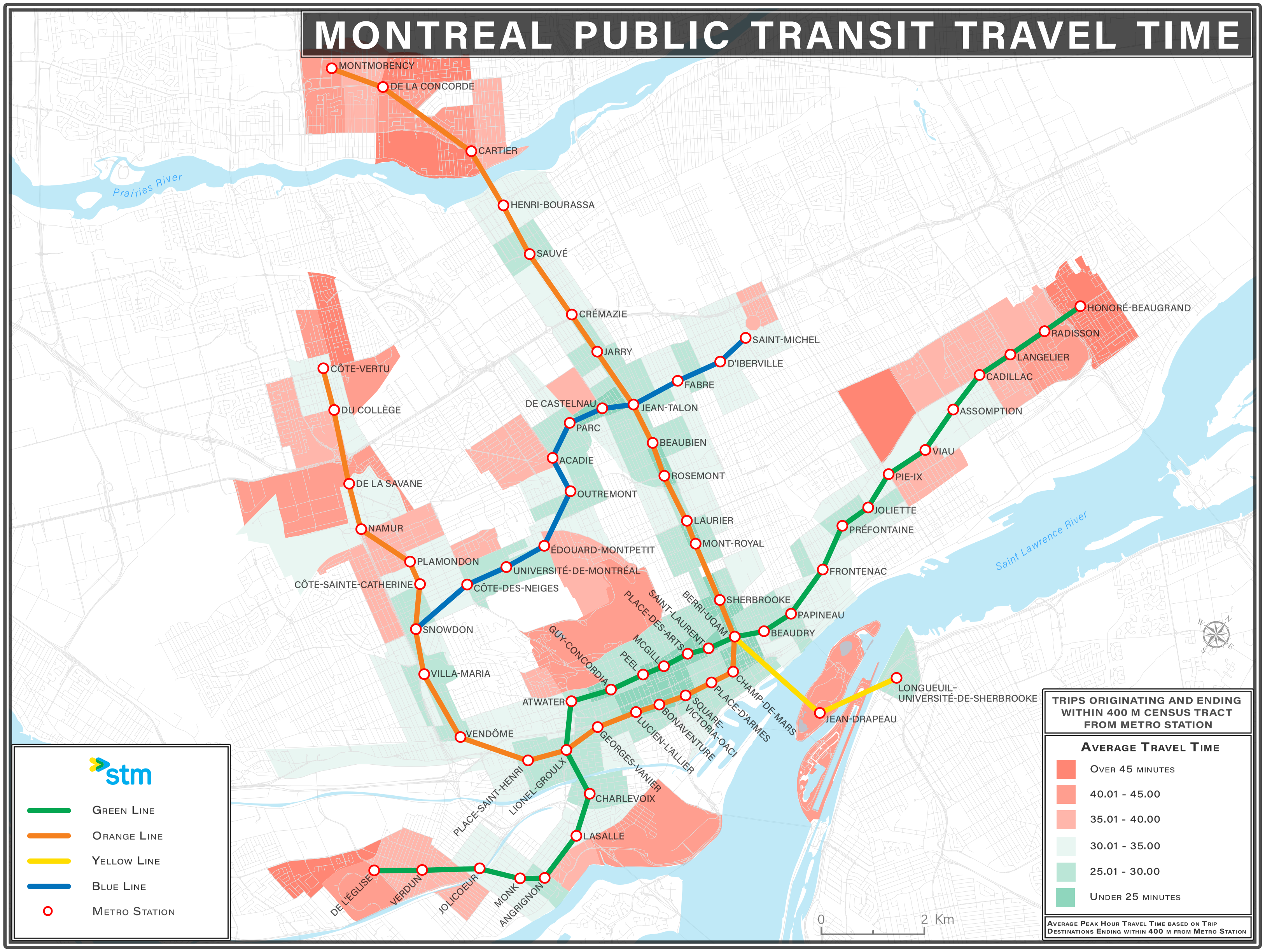


Figure 13: Montreal Public Transit Travel Time – Trips Originating and Ending within 400 metre Census Tract from Metro Station (based on trip destinations)

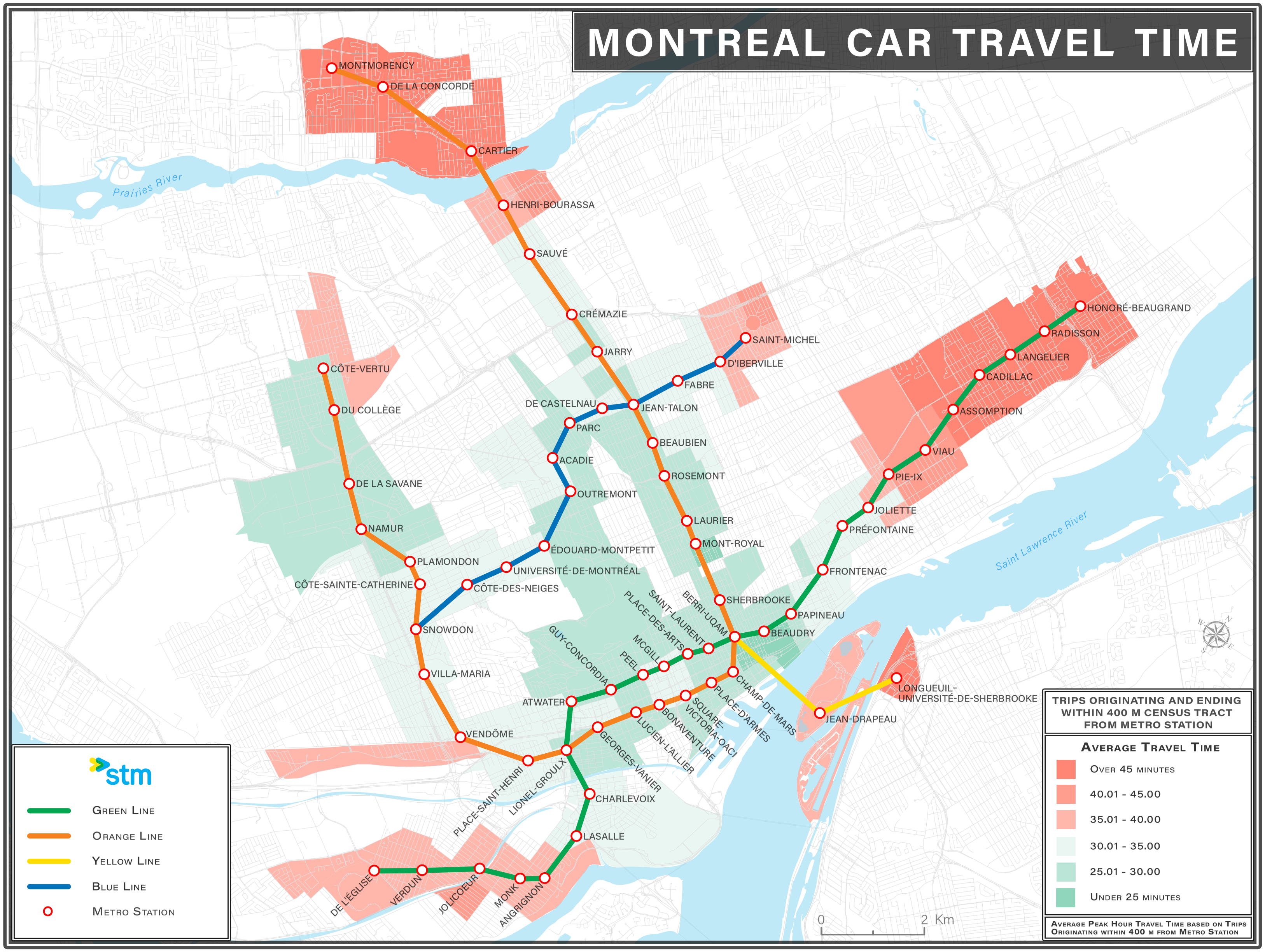


Figure 14: Montreal Car Travel Time – Trips Originating and Ending within 400 metre Census Tract from Metro Station (based on trip origins)

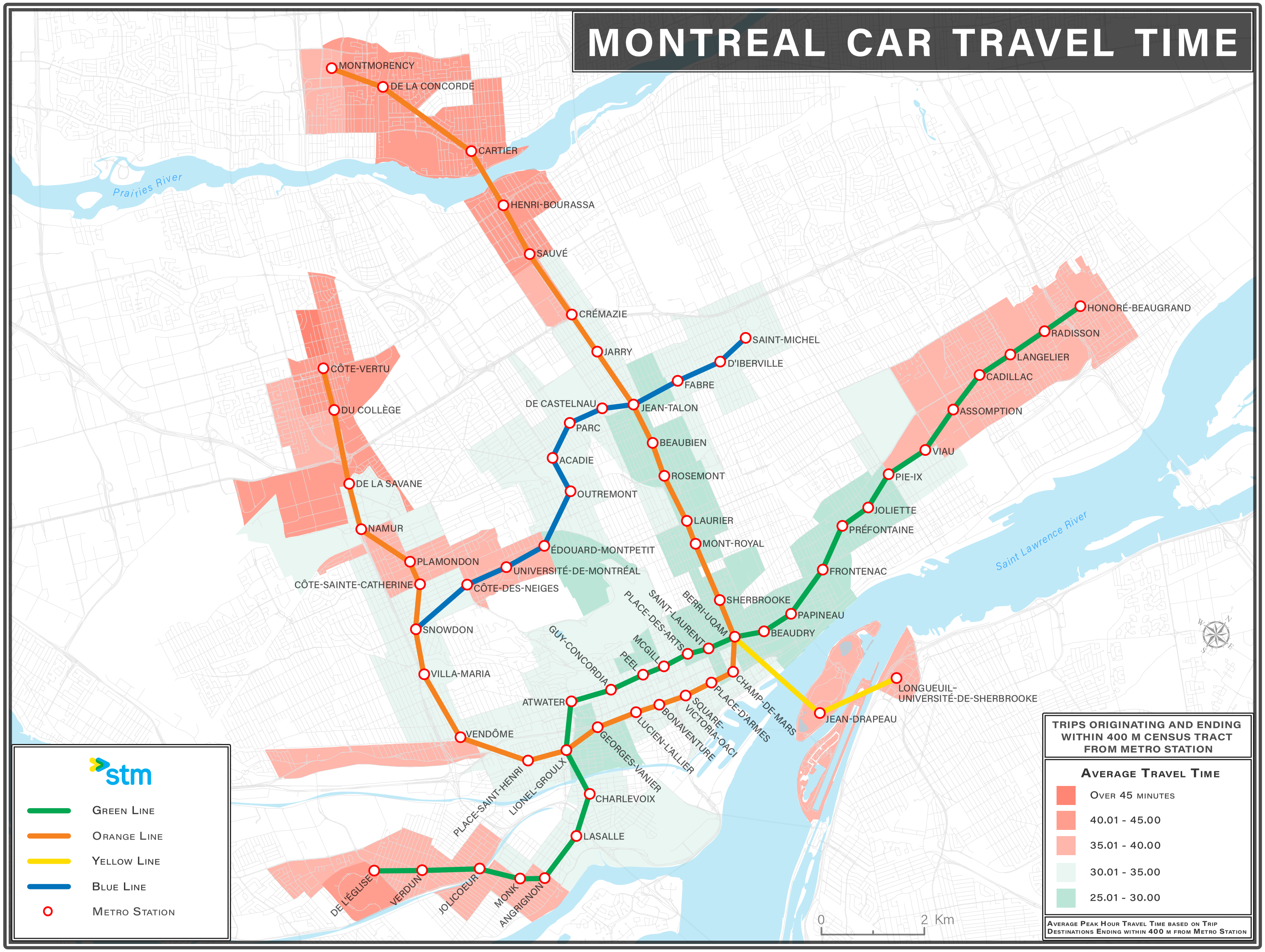


Figure 15: Montreal Car Travel Time – Trips Originating and Ending within 400 metre Census Tract from Metro Station (based on trip destinations)

4.3.3 Montreal Regression Models

Detailed regression model results for the Montreal study area are displayed in Tables B-10 to B-18 (Appendix B) and the coefficients (and their significance values) from the models are summarized in Table 8. Estimated coefficients showed statistically significant relationships, at 99 %, between locational and travel time variables. The sole exception was car travel time statistic for trips destined to 400 metre census tracts around Montreal metro stations. Models were investigated for assumption of heteroskedasticity in the variables by F Statistic and its affiliated significance level. Nearly all of them were homoscedastic showing constant variance, with the same notable exception as listed above.

Table 8: Summary of Regression Coefficients for Montreal

	Public Transit			**Car Travel – Peak Hour**			**Car Travel – Off Peak Hour**		
	(Dependent Variable - Travel time in Minutes)								
	Trip Distance								
	< 10.01 km	< 15.01 km	< 20.01 km	< 10.01 km	< 15.01 km	< 20.01 km	< 10.01 km	< 15.01 km	< 20.01 km
Origin 400m	-8.578***	-12.212***	-15.544***	1.260***	-0.574***	-2.147***	0.809***	0.177***	-0.429***
Destination 400m	-8.331***	-12.183***	-16.207***	3.186***	3.477***	3.427***	0.999***	0.598***	0.031
Origin/Destination 400m	-11.244***	-17.137***	-23.697***	0.751***	-1.786***	-4.313***	0.200***	-1.132***	-2.579***
Origin/Destination 800m	-10.983***	-16.902***	-23.313***	1.077***	-1.566***	-4.109***	0.314***	-1.066***	-2.558***

*Note [1]: Asterisks (***) beside regression coefficients refer to significance values at the following levels: *p<0.1; **p<0.05; ***p<0.01.*

Initial overall coefficient comparisons to Toronto (Table 6) are suggesting higher public transit time savings and nearly identical or marginally faster vehicle (peak and off-peak hour) commutes in our transit-oriented neighbourhood buffer scenarios, than those samples in the entire Montreal region, based on equivalent length trips.

In particular, 10-kilometre transit trips exhibited 11.2 and 11 minutes shorter commutes in the two ideal circumstances (trips from and to 400, and 800, metre buffers around metro stations, respectively) than the equal length trips in Montreal CMA. Ditto at 8.5 and 8.3 minutes time savings for trips solely originating or ending in the identical buffer zones. Car travel times for 10-kilometre trips, regardless of the time of the day of travel and congestion, were almost indistinguishable regardless where the trips originate and end in Montreal.

Public transit commutes during rush hour were, all else being equal, 6 % and 14 % longer than car commutes, for trips in between 400 and 800 metre buffers around transit stations. Interestingly, these were 8 % and 6 % shorter than Toronto public transit trips of the same length.

The subset of data for 15-kilometre trips revealed even greater time savings than previous cases for public transit in all four scenarios. The most substantial differences were, again, in the two circumstances when commuting from and to the areas in the vicinity of Montreal metro stations. These trips were on average 17 minutes shorter than all 15-kilometre public transit trips across the Montreal region. Remarkably, in the same two scenarios car trips were 2 minutes shorter during rush hour, and 1 minute shorter when there is no congestion. It illustrates rather different results than the identical Toronto subset where these trips exhibited 5 minutes longer time values than the remainder of the region.

Employing the regression equation to evaluate and directly compare public transit and car travel times at peak hour for 15-kilometre commutes exposed nearly identical (0.5 % difference) travel times when commuting from and to shorter buffers around metro stations. All else being equal, public transit commutes were 7 % longer than those made by car when traveling from and to larger buffers around metro stations. However, relating the 15-kilometre public transit trips to those in the City of Toronto it was revealed that they were 16 % and 12 % shorter (for commutes between 400 metre, and 800 metres around transit stations, respectively). This fact exemplifies the exceeding trend in time savings for public transit trips between the two cities while adjusting trip lengths from 10 to 15 kilometres.

Travel time differences were further magnified for longer maximum commutes of up to 20 kilometres, upon comparison of optimal four transit-oriented trip scenarios, to the results in the entire Montreal CMA. The largest changes were noted for public transit in two optimal trip origin and destination options where time variances ranged between negative 23 and 24 minutes in contrast to the full region. Identical locational situations showed peak hour car travel times to be 4 minutes shorter and off-peak 3 minutes shorter than the same length trips in Montreal.

Yet again this is an interesting occurrence that was observed beforehand for the models in the 15-kilometre trip lengths data subsets. Stated alternatively, all car trips that are starting and ending in the areas around metro stations are shorter than the overall 15-kilometre car trips in Montreal. Direct comparison of the two transit modes during peak hour, all else being equal, revealed nearly identical transit and vehicle travel times (transit being 2 % shorter) when commutes are conducted between census tracts within 400 metres from metro stations. When buffers were enlarged to 800 metres, traveling in between the encompassing census tracts by public transit was, interestingly, 4 % longer. Montreal's Metro trips were impressively 20 % and 16 % shorter, respectively, than subway trips in Toronto, when maximum commuting distance is 20 kilometres.

4.4 Vancouver Results

4.4.1 Vancouver Study Area Descriptive Statistics

Descriptive statistics for Vancouver are displayed in Table 9. The Vancouver study area, represented by Vancouver CMA, is 18 % smaller than that of Montreal (Table 1) yet it exhibited nearly matching statistics as Montreal (Table 7) for trip characteristics relating to journeys either originating (origin within 400 m, origin within 800 m) or ending (destination within 400 m, destination within 800 m) in census tracts within 400 and 800 metres from Sky Train stations.

Table 9: Vancouver O-D Trip Characteristics

	Transit Travel Time 8 am		Car Travel Time Peak Hours		Car Travel Time Off Peak Hours		Car Travel Distance (km)		Number of O-D Records
	Yes	No	Yes	No	Yes	No	Yes	No	
Origin and Destination within 400 m	44.73	94.49	35.79	50.38	21.49	32.12	14.49	27.55	8,649
Origin and Destination within 800 m	48.11	95.84	37.12	50.75	22.38	32.39	15.28	27.91	15,376
Origin within 400 m	71.30	97.76	43.66	51.32	27.96	32.62	22.43	28.18	44,175
Origin within 800 m	72.81	99.57	44.21	51.81	28.20	32.95	22.59	28.63	58,900
Destination within 400 m	72.05	97.58	47.13	50.48	28.02	32.60	22.51	28.16	44,175
Destination within 800 m	73.42	99.35	47.11	50.78	28.27	32.92	22.69	28.59	58,900

Note: Transit Travel and Car Travel times are based on average travel times expressed in minutes. Number of O-D records shows number of records within buffers.

More importantly, as the epicenter of our study is being characterized by trips that are both beginning and completing in transit-oriented neighbourhoods defined by two buffer zones, disparate trends are emerging in comparison to Montreal and Toronto.

Firstly, absolute public transit travel times exhibited the longest measures at 45 minutes (400 m buffer) and 48 minutes (800 m buffer). These were 41 % and 37 % longer than overall average transit trips in Montreal for the same scenarios; and 3 % and 5 % longer than those same commutes in Toronto.

Average transit travel times are closely tied to distances and the extent of the rail network. Vancouver's SkyTrain is the longest of the three rail networks in the research (Table 3) which consequently led to longest average commutes of all three research areas. It also inadvertently affected travel distances by car which similarly revealed the highest values across three cities in these two categories. However, in the regression analysis section for Vancouver, distances will be able to be controlled for, accordingly enabling further and more accurate cross comparisons of transit times across the study areas.

Secondly, it is the only urban region in Canada with transit rail infrastructure in our research, where traveling by car is substantially faster than commuting by public transit measured at peak-times at 8 am, for our two transit-centric scenarios. These were, in Vancouver's case, commutes from and to districts around Sky Train stations. More specifically transit travel times were 25 % longer than those made by car in census tracts within 400 metres from Sky Train stations, while those in 800 metre buffers were 30 % longer.

Even at the longest reported travel distances, car travel times are quite comparable to other cities. For instance, if traveling from and to 400 metre buffers from SkyTrain stations, average traveled distances are 13 % longer than Toronto (Table 5) yet travel times are 4 % faster when not accounting for congestion, and impressively 18 % faster during rush hour (Table 9). A corresponding trend is witnessed in comparison of census tracts within 800 metres from Sky Train stations. This could potentially lead to a separate argument about more efficient, less congested and better inter-connected road network in Vancouver than Toronto.

4.4.2 Vancouver Spatial Analysis

Thematic maps showing spatial variation of commute times for Vancouver metropolitan area, designed to represent trips at peak-hour for census tracts originating and ending within 400 metre distance from Sky Train stations, are displayed in figures 16 and 17 for public transit, and figures 18 and 19 for trips when traveling by car. In the context of Vancouver public transit, when the average commutes are generated based on trip origins (Figure 16), comparable geographic distribution is evidenced as in Toronto (Figure 8) and Montreal (Figure 12). More specifically, the most efficient times are located around stations in the centralized downtown area (peninsula south east of English Bay) which incrementally increase towards suburban communities.

Of the three rapid transit rail lines, neighbourhoods along the Expo line show the fastest public transit commutes (30.01-35, 35.01-40 minute categories). Areas associated with the Canada line, predominantly when travelling from airport and other adjacent stations at the end of the SkyTrain route, experience one of the highest public transit commutes, often over 55 minutes.

Related spatial clustering of areas with high public transit time values is present at the ending branches of the Millennium (Burquitlam to Lafarge Lake–Douglas stations) and Expo (Scott Road to King George stations) lines. Figure 17, contrarily shows public transit commutes, based on census tracts as their destinations, which in comparison to trips based on origin, exhibited minimal differences in spatial pattern. These differences occurred in the central part of the city where few areas generally exhibited 5-10 minute shorter commutes.

Commuting by car from and to neighbourhoods around Sky Train stations is much faster (Figure 18) than public transit, in most of the central part of Vancouver metropolitan region, which is averaging impressive 25.01-30, or 30.01-35 minute commutes (based on census tracts as trip origins). Alternatively, in the scenario based on census tracts as trip destinations (Figure 19), average peak-hour car travel times are even more superior in the entire area than previous example(s), except for neighbourhoods east of, and encompassing the southern portion of the Canada line.

Complementary maps based on evaluation of the full study region are showing shortest public transit commutes in neighbourhoods around Sky Train stations, when trips are based both on origins (Figure A-9) and destinations (Figure A-10). Contrarily, suburban areas in both examples are showing the highest transit times. The values increase uniformly from central business district outwards to suburban communities.

Car commutes, as assessed by calculating travel time averages based on census tracts as trip origin, for the full Vancouver metropolitan region, are indicating superior values in the central area between mid sections of the Millennium and Expo lines (Figure A-11). Upon changing vehicular average transit travel time calculations to be based on census tract as trip destinations, suburban areas in between the eastern portions of the Millennium and Expo lines are displaying the shortest car commutes in all the region. In the same scenario, the longest commutes are experienced in Downtown Vancouver and neighbourhoods along the Canada line.

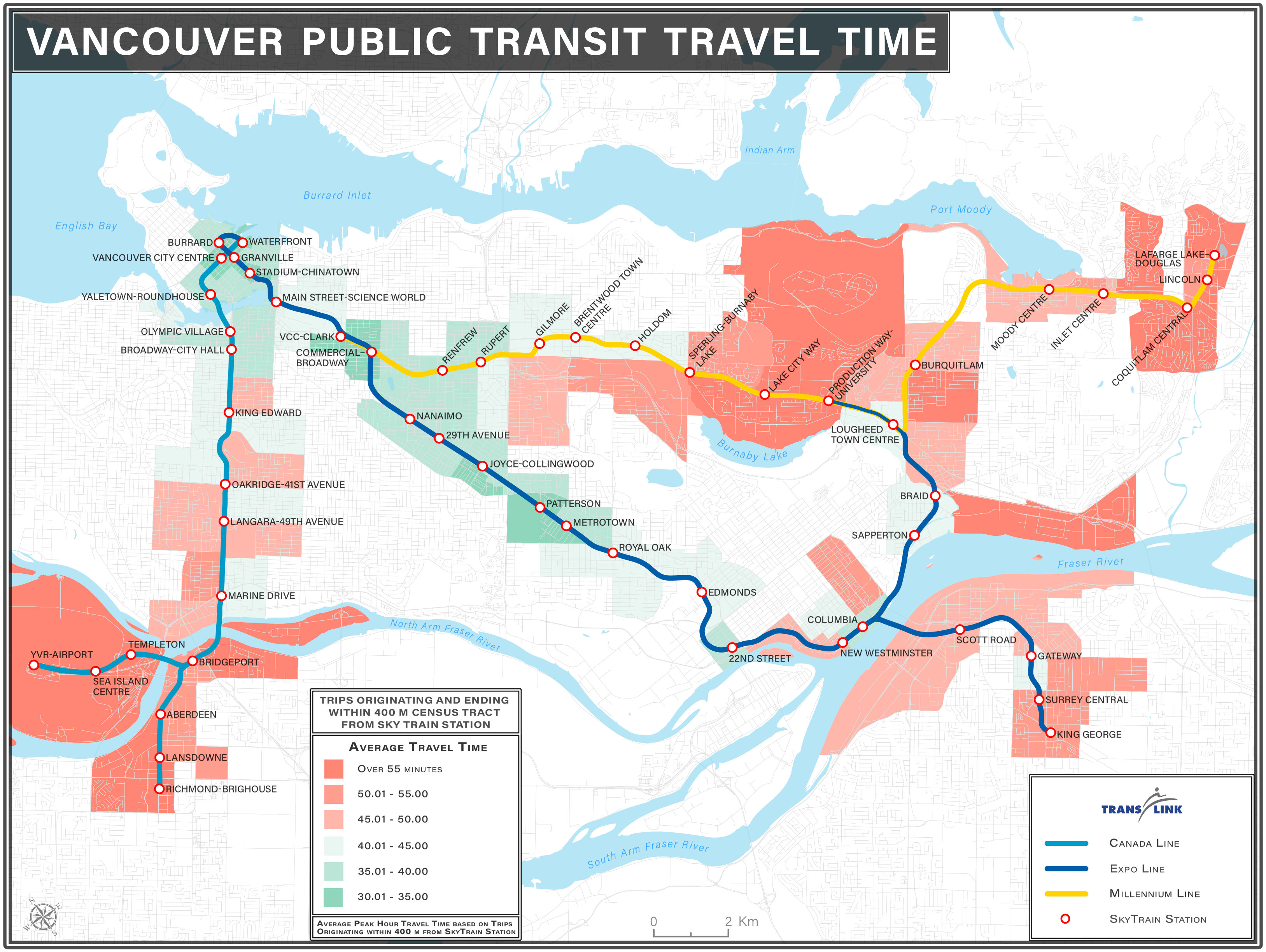


Figure 16: Vancouver Public Transit Travel Time – Trips Originating and Ending within 400 metre Census Tract from Sky Train Station (based on trip origins)

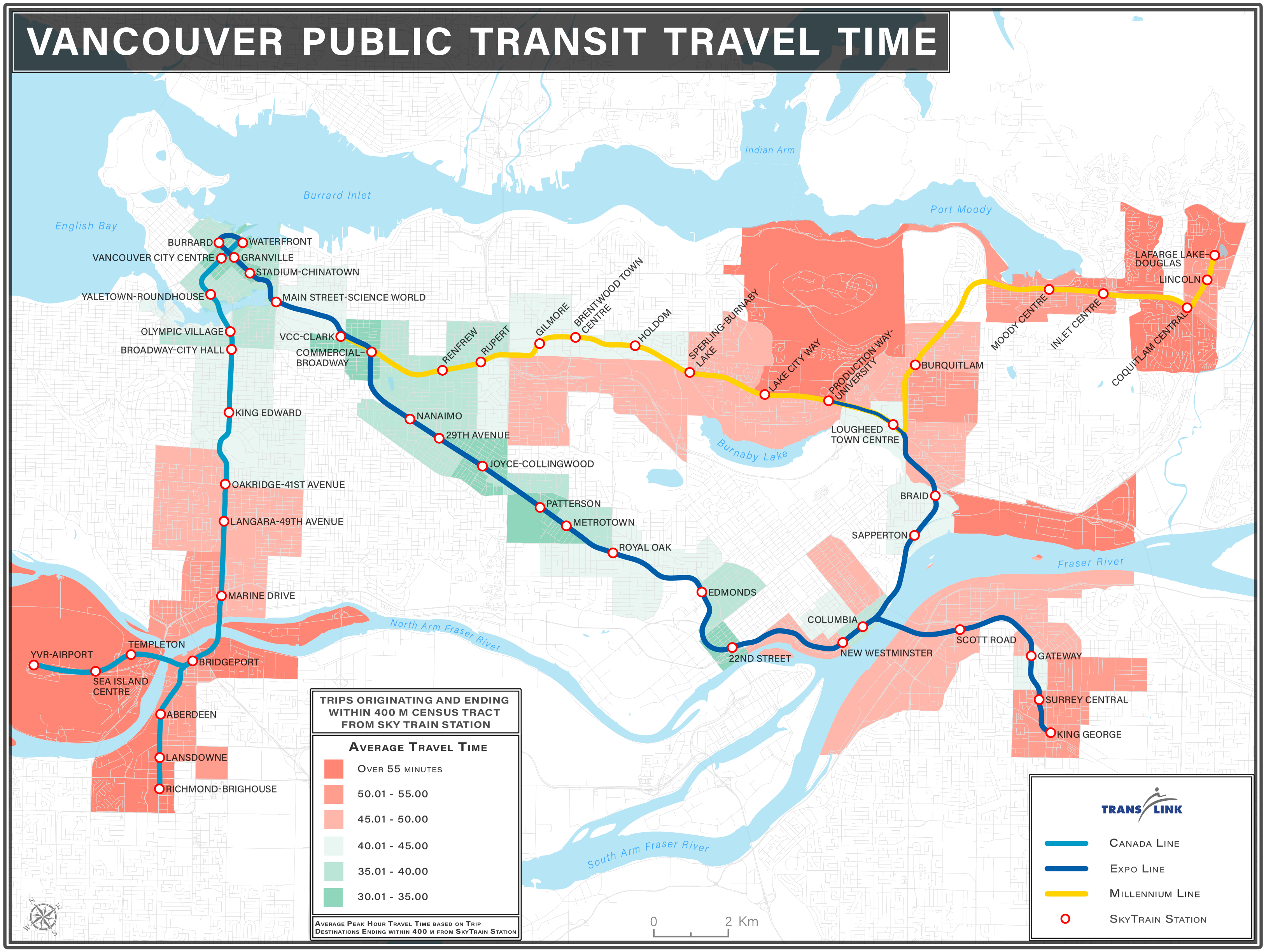


Figure 17: Vancouver Public Transit Travel Time – Trips Originating and Ending within 400 metre Census Tract from Sky Train Station (based on trip destinations)

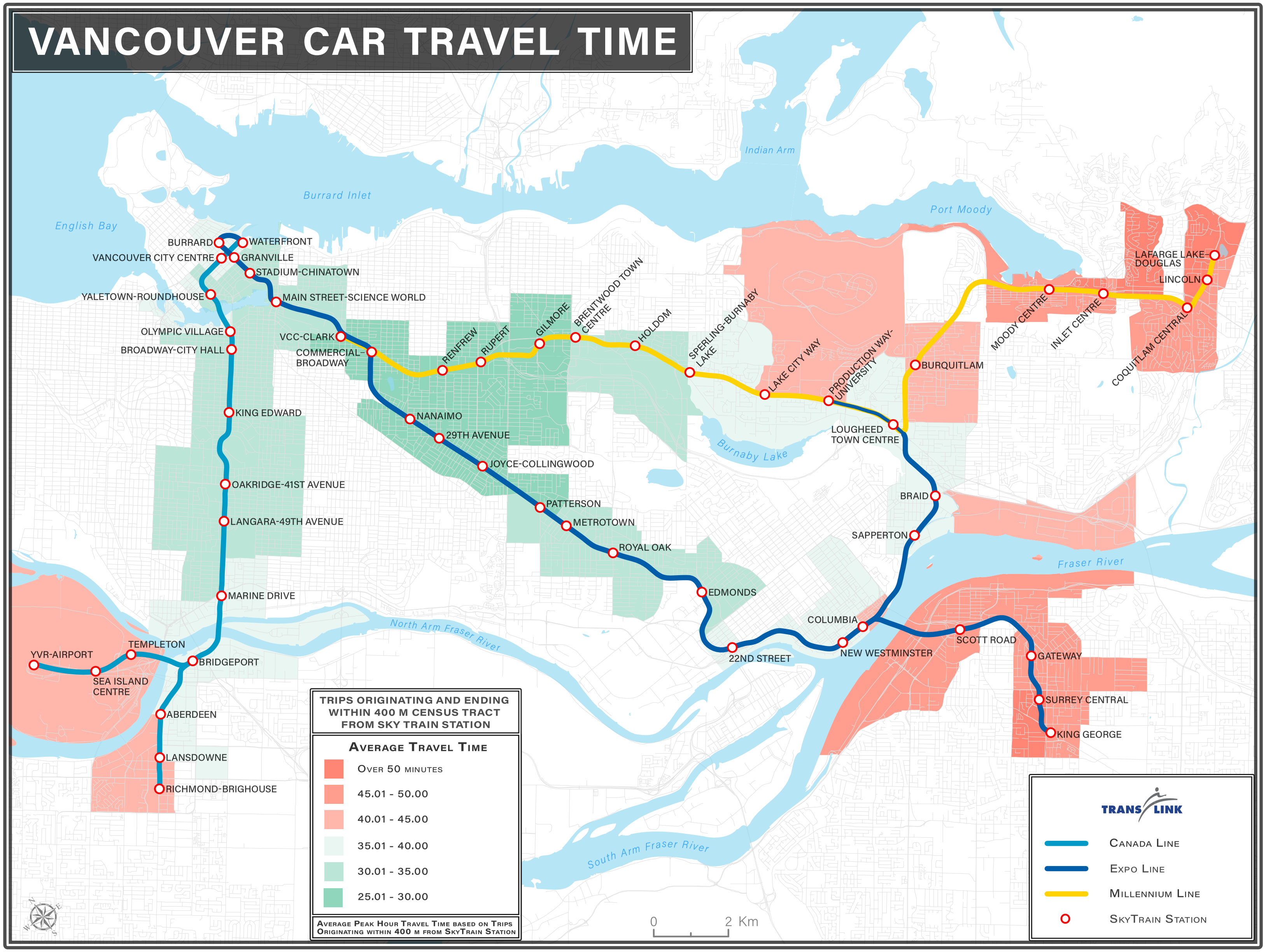


Figure 18: Vancouver Car Travel Time – Trips Originating and Ending within 400 metre Census Tract from Sky Train Station (based on trip origins)

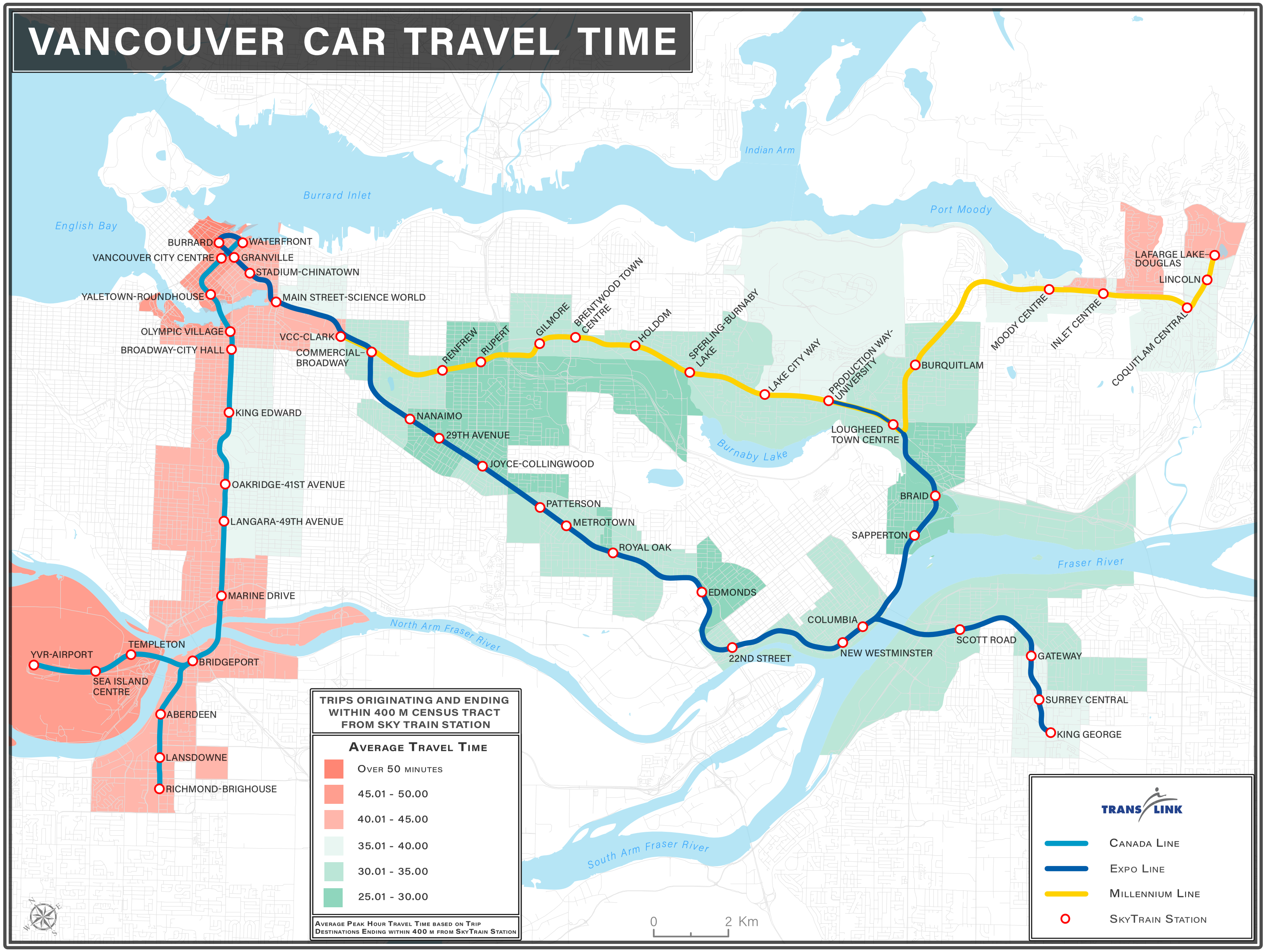


Figure 19: Vancouver Car Travel Time – Trips Originating and Ending within 400 metre Census Tract from Sky Train Station (based on trip destinations)

4.4.3 Vancouver Regression Models

In total, nine regression models were generated for the Vancouver study area. The estimated coefficients and their corresponding significance values are shown in Table 10. Detailed regression outputs for three trip distance scenarios and three transportation mode types are listed in Tables B-19 to B-27 (Appendix B). Explanatory locational variables associated with transit-oriented neighbourhoods, as defined by our four origin and destination trip scenarios, proved to be statistically significant determinants at 99 % level, of average travel times, expressed in minutes, in nearly all examples.

Three exceptions were noted where coefficients were not statistically significant. They occurred in samples for peak hour car travel time for 15-kilometre trips originating and ending in census tracts that are within 800 metre buffers from Sky Train stations; and off-peak hour car travel time variable when traveling from and to 400, and 800 metre, buffers in instances of 10 kilometre commutes. All models, with identical exceptions as indicated above, were homoscedastic indicating constant variance as measure by F statistic.

Table 10: Summary of Regression Coefficients for Vancouver

	Public Transit			**Car Travel – Peak Hour**			**Car Travel – Off Peak Hour**		
	(Dependent Variable - Travel time in Minutes)								
	Trip Distance								
	< 10.01 km	< 15.01 km	< 20.01 km	< 10.01 km	< 15.01 km	< 20.01 km	< 10.01 km	< 15.01 km	< 20.01 km
Origin 400m	-5.334***	-8.822***	-11.580***	2.147***	1.505***	0.597***	0.895***	0.365***	-0.251***
Destination 400m	-5.396***	-8.808***	-11.463***	2.390***	1.960***	1.438***	0.811***	0.322***	-0.300***
Origin/Destination 400m	-8.390***	-13.962***	-18.573***	1.254***	-0.477***	-2.085***	0.120	-0.907***	-2.008***
Origin/Destination 800m	-7.425***	-12.319***	-16.615***	1.000***	-0.134	-1.356***	0.006	-0.704***	-1.543***

*Note [1]: Asterisks (***) beside regression coefficients refer to significance values at the following levels: *p<0.1; **p<0.05; ***p<0.01.*

Upon preliminary assessment of the overall coefficients among the three cities, the early conclusion can be made that public transit results in Vancouver are analogous to those in Toronto, while car travel times, irrespective of congestion, are comparable to Montreal.

Under the public transit 10-kilometre subset of data, it can be observed that trips associated with either origin or destination areas around SkyTrain stations have favorable travel times in comparison to the overall transit trips in the study area of equal distance. The largest differences in transit trips occurred when commuting from and to 400 metre buffers from the stations.

In this scenario, all else being equal, the average commuter spent 8 minutes less traveling, with 31 % explained variance, than if taking 10-kilometre trips by public transit in overall Vancouver CMA outside of noted buffers. In the same subset of data, off-peak vehicle travel time was identical to the trips conducted in the remainder of the region. However, when traveling during rush hour, trips associated with our buffers were, to some extent longer, ranging from a minute (traveling from and to 400 metre buffers around Sky Train stations) to 2 minutes (trips either starting or ending in the 400 metre buffers).

A compelling trend was exhibited when contrasting public transit and car travel times during peak hour for 10-kilometre trip distances (Table B-19, Table B-20) which did not occur to this extent in the identical comparisons in Toronto and Montreal study areas. It was discovered, upon applying constants and coefficients to the linear regression equation, that public transit trips were 52 % longer than car when commuting between 400 metre walking distance buffers from Sky Train stations. When commutes are conducted in between larger 800 metre buffers around the stations those differences become even more pronounced with transit trips being 61 % longer.

The exaggerated differences were counter intuitive from our established hypotheses that transit trips would be expected to be faster or highly comparable to car in these optimal scenarios. This, again, could be indicative of unusually faster vehicle travel times than other factors, as briefly alluded to in the descriptive analysis section for Vancouver, and later shown in contrasting absolute transit times which showed somewhat comparable values among the cities in these commuting circumstances. Thus, when trips are segmented based on 10-kilometre distances, these profound travel time changes between the two modes are conceivably implying fast and effective road networks with high interconnectedness among transit-oriented neighbourhoods in Vancouver, to enable and explain efficient car commutes.

Increasing and delimiting commuting distances to 15 kilometres had most noticeable effects on public transit trips, specifically when commuting from and to the areas around SkyTrain stations. All else being equal, transit commutes were 14 and 12 minutes shorter for inter transit-oriented neighbourhood trips for respective 400 and 800-metre buffers. The two scenarios correspondingly explained 41 and 49 % percent of variance in travel times (Table B-22).

Car travel times, regardless of the congestion, showed nearly identical coefficients, indicating that longer commutes in Vancouver will exhibit approximately same travel times regardless of trips origins and destinations. Contrasting transit to vehicle, 15-kilometre commutes (Table B-22, Table B-23) by way of the linear regression equation in the two optimum transit circumstances showed that public transit trips were 37 % longer for commutes between 400 metre buffers, and 44 % longer between 800 metre buffers, from Sky Train stations.

As expected, the data subset of 20-kilometre maximum distance trips, showed highest time savings indicative of commutes made by Sky Train than other public transit modes. This is exhibited as 19 minutes shorter trips in between 400 metre buffers from Sky Train stations, and 17 minutes shorter trips when traveling in between neighbourhoods in 800 metre buffers from the stations. These two scenarios also presented high variances in explaining travel times, at 43 % and 56 % respectively (Table B-25). Car trips in the same respective buffers exhibited slightly shorter commutes than car trips in the region, by 2 and 1 minutes, respectively, regardless of congestion. Upon comparison of peak hour public transit to car travel times (Table B-26) it was determined that the former are 32 % and 38 % longer in the corresponding and previously stated commuting circumstances. It can be concluded, relating to direct comparisons of peak hour transit and car commutes, that as the trip distances increase travel time differences lessen. In the Vancouver region, however, these differences were substantially larger, than those in the Toronto and Montreal study areas.

Comparing the absolute public transit peak hour travel times for the three cities in this research, based on three trip distance scenarios, the following results were revealed when analyzing the most optimal transit oriented commuting option (commuting from and to 400 metre buffers from transit stations).

From the perspective of Montreal, which recorded the lowest transit commute times in the study at 26.94 minutes for 10-kilometre trips, 29.61 minutes for 15-kilometre trips, and 31.13 minutes for 20-kilometre trips; the transit trips of equal length in Toronto were 9 %, 19 % and 25 % longer respectively; while for Vancouver the equivalent corresponding transit commutes were 10 %, 16 % and 23 % longer.

The second most optimal transit-oriented commute scenario, depicted by trips from and to census tracts defined by 800 walking distance buffers around transit stations, likewise showed fastest public transit commutes for Montreal. They were recorded at 29.09 minutes for 10-kilometre trips, 32.22 minutes for 15-kilometre trips, and 34.11 minutes for 20-kilometre trips. In comparison, the corresponding length trips for the identical transit-oriented commutes in Toronto were 6 %, 13 % and 19 % longer; whereas in Vancouver transit travel times were elongated by 7 %, 13 % and 20 % respectively. The absolute travel time differences in this second-best option scenario are lowest among the three cities.

The transit trips described in the last two instances are logically characterized by travelling with the fastest transit commute mode, which is one of the types of urban rail systems in the research (Table 3). The observations of the optimal urban travel public transit commutes scenarios lead to the conclusion that daily trips conducted by Montreal's Metro will exhibit fastest transit travel times of the three cities, while Toronto's subway and Vancouver's Sky Train lagged behind but showed highly comparable, and in some instances, nearly identical travel times between them.

CHAPTER 5 CONCLUSIONS

5.1 Introduction

This research paper offers spatial analysis of travel times by two major modes of travel, public transit and automobile, in transit oriented neighbourhoods of Toronto, Montreal and Vancouver. These neighbourhoods are defined by 400 and 800 metre walking distance geometric network buffers from major rail transit stations represented by subway, metro or SkyTrain systems, respectively. The aim of the study is to identify whether commutes that either start, end, or both start and end, in transit oriented neighbourhoods offer comparable travel times between automobile and public transit. Transportation planning theory and transit agencies planning practices, as it was asserted in the review of literature, are advocating increased transit usage in these metropolitan neighbourhoods which need to be justified and supported by competitive commute times.

To achieve this, Origin-Destination (O-D) matrices were initially estimated for public transit and automobile for the study areas (from and to the centroid of each census tract) based on shortest route algorithms. Following this they were turned into comprehensive GIS-based database and spatially segmented for various travel scenarios. The narrower emphasis of the research, and this summary, were *peak-hour* trips that were geographically defined as starting and ending in transit oriented neighbourhoods, hypothesizing most comparable travel times between the two modes. We initiated empirical research with descriptive statistics followed by mapping based on submatrices of various travel scenarios. Subsequently we developed the linear regression models which explored the effects of trip distances on travel times in transit oriented neighbourhoods.

5.2 Summary of the results

Descriptive statistics in Toronto show that trips which originate and end in neighbourhoods around subway stations for peak-hour at 8 am were on average 43 minutes (400 m buffer) and 46 minutes (800 m buffer), with comparable car travel times at 44 and 45 minutes, respectively. In the equal commuting circumstance in Montreal, journeys from and to 400 m buffers, at peak hours showed identical average commutes by public transit and car at around 32 minutes, while average automobile travel time from and to 800 m buffers was 33 minutes with transit being 5 % longer.

Vancouver exhibited the highest public transit average travel times of the three cities at 45 minutes (400 m buffer) and 48 minutes (800 m buffer) while the average car travel times when commuting from and to areas around SkyTrain stations were 36 minutes (400 m buffer) and 37 minutes (800 m buffer). Vancouver is the only urban region in Canada with transit rail infrastructure in our research, where traveling by car is substantially faster than commuting by public transit measured at peak-times at 8 am, for our two transit-centric scenarios. These transit commutes were 25 % and 30 % longer than car. The descriptive statistics are relative and tied to the interpretation of each individual city due to the different length of rail network which directly influenced trip distances and hence average travel time values (more trips across longer routes). Cross comparison among three cities were more compatible in linear regression models as trip distances were controlled for.

Spatial analysis was conducted with thematic maps depicting average travel times at *peak-hour* when travelling from and to transit oriented neighbourhoods (400 m buffer) with census tract as the geographic unit. Estimates were based on two scenarios: whether trips originated, or their destinations ended, in the areas around transit stations. For public transit several commonalities were exhibited in all three cities with spatial clustering of census tracts with lowest average travel time categories located in Central Business Districts (CBD), downtown area and central city area, especially in neighbourhoods around inter-connecting transit stations. Travel time would generally uniformly increase outwards toward the zones around transit stations on the city outskirts and suburbia. Interestingly, car travel time had similar geographic distribution. Overall, Toronto and Montreal exhibited comparable travel time values between transit and automobile with several neighbourhood specific spatial variations, such as that transit was faster in some CBD and downtown areas, while car was faster in midtown and outer city areas. On the contrary, in Vancouver, automobile travel time was almost continuously shorter than public transit, with very few exceptions such as longer car travel commutes that originated in downtown.

The above results are in accordance with the advanced models (using detailed travel time calculations including access, egress, transfers, etc.) of the study conducted in Greater Helsinki Area which compared public transit and car travel time with clustering of highly comparable results between two modes in downtown area and along the rail lines (Salonen & Toivonen, 2013).

The linear regression models were estimated for public transit and car travel times as dependent variables based on delimited trip distances of 10, 15 and 20 kilometres (km) to reflect realistic daily commutes and allow comparable cross examinations for three cities. The independent, or explanatory, variables were the presence of census tracts in one of the several transit oriented neighbourhood scenarios. The estimated coefficients for transit-oriented areas exhibited high statistical significance at 99 % level in explaining transit travel times.

Public transit trips that originated and ended in transit proximity communities of Toronto, Montreal and Vancouver were significantly shorter, all else being equal, than all other public transit trips of the equal length in their respective study regions. Increasing trip distances would result in incrementally enlarged time savings. Depending on the length of the trips, and distances from transit stations where trips started and ended (400 m or 800 m), these savings ranged from 8.4 to 16 minutes in Toronto, 11 to 23.69 minutes in Montreal, and 7.4 to 18.5 minutes in Vancouver. The results contribute to the enduring argument that living and commuting from and to transit-oriented neighbourhoods result in substantially beneficial transit travel times than the rest of the metropolitan area. However, this was expected as trips between transit oriented communities would imply traveling by rail, which is the fastest public transportation travel mode.

Automobile trips were analogous to the trips in the rest of the region for same trip lengths. In Toronto travelling from and to transit oriented neighbourhoods exhibited longer travel times than the remainder of the study area, ranging from 3.6 to 5.1 minutes. In Montreal and Vancouver results were highly comparable, with longer trips (10 and 15 kilometre) resulting even in small time savings. These ranged from 1.6 to 4.3 minutes in Montreal, and up to 2 minutes in Vancouver.

Applying coefficient and constant values to the linear regression equation the results highlighted some alluring and counter intuitive outcomes (Table 11). They revealed that in Toronto transit travel time values for peak-hour 10-km commutes were 15 % higher than car (from and to 400 m buffers around subway station). When the trip distance is increased to 15-km transit travel time was 3 % longer, and for 20-km, 1 % shorter. What's more, transit commutes were exacerbated when based upon traveling from and to transit-oriented neighbourhood delineated by a larger 800 m buffer, where they exhibited 21 % , 8 % and 3 % larger values than car for the respective 10, 15 and 20-km trip lengths.

These results are relatively non-instinctive as the expectation would rest on public transit trips to demonstrate either highly comparable or superior travel times during rush hour. Increased trip length is also indicative of the narrower comparability between public transportation and vehicular travel times.

In the similar manner, when coefficients and constant values were applied to Montreal regression models, public transit trips were longer than car (Table 11). Public transit commutes for maximum 10-km trip lengths during rush hour were 6 % and 14 % longer than car commutes (for trips in between 400, and in between 800 metre buffers around transit stations, respectively). Increasing the distance to 15-km made the travel times more comparable, with nearly identical (0.5 % difference) travel times when commuting from and to shorter buffers around metro stations, and 7 % longer than those made by car when traveling from and to larger buffers around metro stations. In the same circumstances for 20-km trips transit travel was 2 % shorter, and 4 % longer, for 400 m and 800 m buffers respectively.

The differences between public transit and automobile travel were most pronounced in the City of Vancouver (Table 11). It was estimated, upon applying constants and coefficients to the linear regression equation, that public transit trips were 52 % longer than car when commuting between 400 metre walking distance buffers from Sky Train stations. When these commutes are conducted in between larger 800 metre buffers around the stations those differences become even more distinct with transit trips being 61 % longer. For 15-kilometre commutes public transit trips were 37 % longer for trips between 400 metre buffers, and 44 % longer between 800 metre buffers, from Sky Train stations. Upon comparison of 20-km peak hour public transit and car trips, it was determined that the former are 32 % and 38 % longer in the corresponding and previously stated commuting circumstances.

Table 11: Summary of Travel Times

	Toronto						**Montreal**						**Vancouver**					
	(Travel time in Minutes, Public Transit – PT, Automobile - A)																	
	Trip Distance (10, 15 or 20 km)																	
	PT	A	PT	A	PT	A	PT	A	PT	A	PT	A	PT	A	PT	A	PT	A
	< 10.01 km		< 15.01 km		< 20.01 km		< 10.01 km		< 15.01 km		< 20.01 km		< 10.01 km		< 15.01 km		< 20.01 km	
Origin/Destination 400m	29.3	25.4	35.1	34.1	38.9	39.2	26.9	25.5	29.6	29.7	31.1	31.8	29.7	19.5	34.3	25.0	38.3	29.0
Origin/Destination 800m	30.9	25.4	36.5	33.9	40.5	39.1	29.1	25.6	32.2	30.2	34.1	32.5	31.0	19.2	36.6	25.3	41.1	29.8

Note : Travel times calculations were based on applying coefficients and constants from appropriate models to the linear regression equation (Equation 1).

Relating the absolute public transit peak hour travel times for the three cities in this research, based on three trip distance scenarios, the following results were revealed when analyzing the most optimal transit oriented commuting option (commuting from and to 400 metre buffers from transit stations). From the perspective of Montreal, which recorded the lowest transit commute times in the study at 26.94 minutes for 10-kilometre trips, 29.61 minutes for 15-kilometre trips, and 31.13 minutes for 20-kilometre trips; the transit trips of equal length in Toronto were 9 %, 19 % and 25 % longer respectively; while for Vancouver the equivalent corresponding transit commutes were 10 %, 16 % and 23 % longer (Table 11).

5.3 Suggestions for future research

This research paper has relied upon Origin-Destination estimates of travel time and related trip characteristics (*peak* and *off-peak* hour, and distances travelled by car) which were initially calculated by Google API for car, and GTFS for public transit. GTFS calculations inherently included access, egress, transfers, waiting times, routing, up-to-date schedules and congestion (for *peak-hour* scenario). As affirmed in the literature review, researchers are stressing implementing advanced and detailed travel time calculations, which were exhibited in our public transit calculations. Vehicle travel calculations applied the highly recommended and precise technique of Google API however did not account for one particular segment of vehicular travel which is parking. Systematic inclusion of a parking variable could be counted in travel time calculations to represent time spent to find a parking space, and necessary walking times to and from the parking space. Researchers have suggested several methodologies, the simple one being average distances and average times per different city areas. We could then apply more precise *door-to-door* approach which would somewhat add to vehicle travel times.

Considering the number of records in the datasets in our study (Table 1) the spatial autoregressive (SAR) models were not applied at the time of the methodological and analytical research. It is therefore suggested to be undertaken as a part of a future research.

As I have observed land use factors are heavily studied topics in transportation literature, especially in TOD context, and travel time has been noted as a crucial parameter in transit planning ranging from mode choice selection to cost benefit analysis.

The research that directly links land use factors and travel time in TOD or other spatially defined concepts could benefit from assessing and quantifying relations between them. These land factors, and some of the suggested variables that could be used are: density (variable of interest such as dwelling units, building floor area per unit area), diversity (different land uses in a given area), design (street network characteristics within an area measured as average block size, number of intersections per square mile, average street widths), destination accessibility (ease of trip access to trip attractions, distance to central business district). Demographic, environmental and socio-economic variables could also be highly important factors. Some additional suggestions would include using a smaller geographic unit or grid size, as census tracts can be non-uniform in size; repeating the study in a few years to asses potential travel time savings which could be used in assessments of economic impact and congestion; design and implement survey data; and geographic study focus on O-D sub-matrices concentrating on different areas. All of these could complement and enhance our research.

5.4 Recommendations

Canadian metropolitan areas have been experiencing large investments in public transit infrastructure. One of the major cited reasons is to improve commute times which were identified as a highly important factor on the assessment of transportation policies. Simultaneously, the agenda of urban planning agencies, supported by vast academic research, is to adopt transit oriented neighbourhoods and developments around transit stations, whose major goal is to increase transit ridership. Ideal urban planning discourse is suggested where both living and working arrangements are in the vicinities around transit stations

In this paper we investigated whether travel times by transit are faster than automobile for neighbourhoods near transit stations in three Canadian cities with highly developed transit infrastructure: Toronto, Montreal and Vancouver. Few models were developed, however, the ones depicting optimal transit-oriented scenario were trips that start and end in neighbourhoods around transit stations.

The synopsis of the major findings are as follows. Descriptive statistics show us that Toronto and Montreal have nearly identical travel times, while Vancouver transit trips were 25-30 % longer than car.

Maps further elaborate and confirm the same theme with added variations of spatial patterns and geographic distributions. Linear regression models were able to subset data based on several trip lengths representing daily 10, 15 and 20-km commutes. Largest differences between public transit and car were observed in shortest trip length and differences narrowed down as the trip lengths increased. We will illustrate with empirical example showing results for 10-km trips (detailed summary is presented in previous section 5.2). Depending on the size of the buffer around major transit stations (400 or 800 m), 10-km transit trips were 15 % and 21% longer in Toronto; 6 % and 14 % longer in Montreal; and staggeringly 52 % and 61 % longer in Vancouver, than trips made by private automobile. Our hypothesis shows that transit trips, even in transit-centric optimal scenario, are not faster than car and are at best comparable.

Transit travel times must strive to be competitive with car. However, they will rarely provide sufficient influence to massively shift travel mode share to transit for most commuters. To attract ridership and justify transit investments focus should be placed on other factors instead such as: reliability, coverage, convenience, comfort, environmental factors and very importantly cost.

Availability is an important factor as our cities continue to grow and expand, hence transit must be provided both near one's trip origin and destination, at adequate times. The size and connectivity of the transit system are necessary elements for high ridership as well. The more that transit provides coverage across the region and connectivity between origins and destinations, the greater the potential ridership.

Direct connections with minimal transfers are another critical factor in mode choice. In that respect having longer lines, with minimal inter-modal connections, for each respective travel modes even with moderate speed might be beneficial in attracting more commuters. Public transit should also provide higher frequencies and greater duration throughout the day.

In a recent transportation survey respondents mentioned that services run on time for fewer than 80 per cent of journeys. In the same survey 70 per cent of respondents indicated they are aware of public transport alternatives to car travel for the journeys they make, but they appear not to have accurate information on the costs and travel times by alternative modes. Having a reliable transit system, while advocating lower costs comparing to auto ownership, should be one of the most imperative factors in attracting ridership and promoting public transit.

APPENDIX A

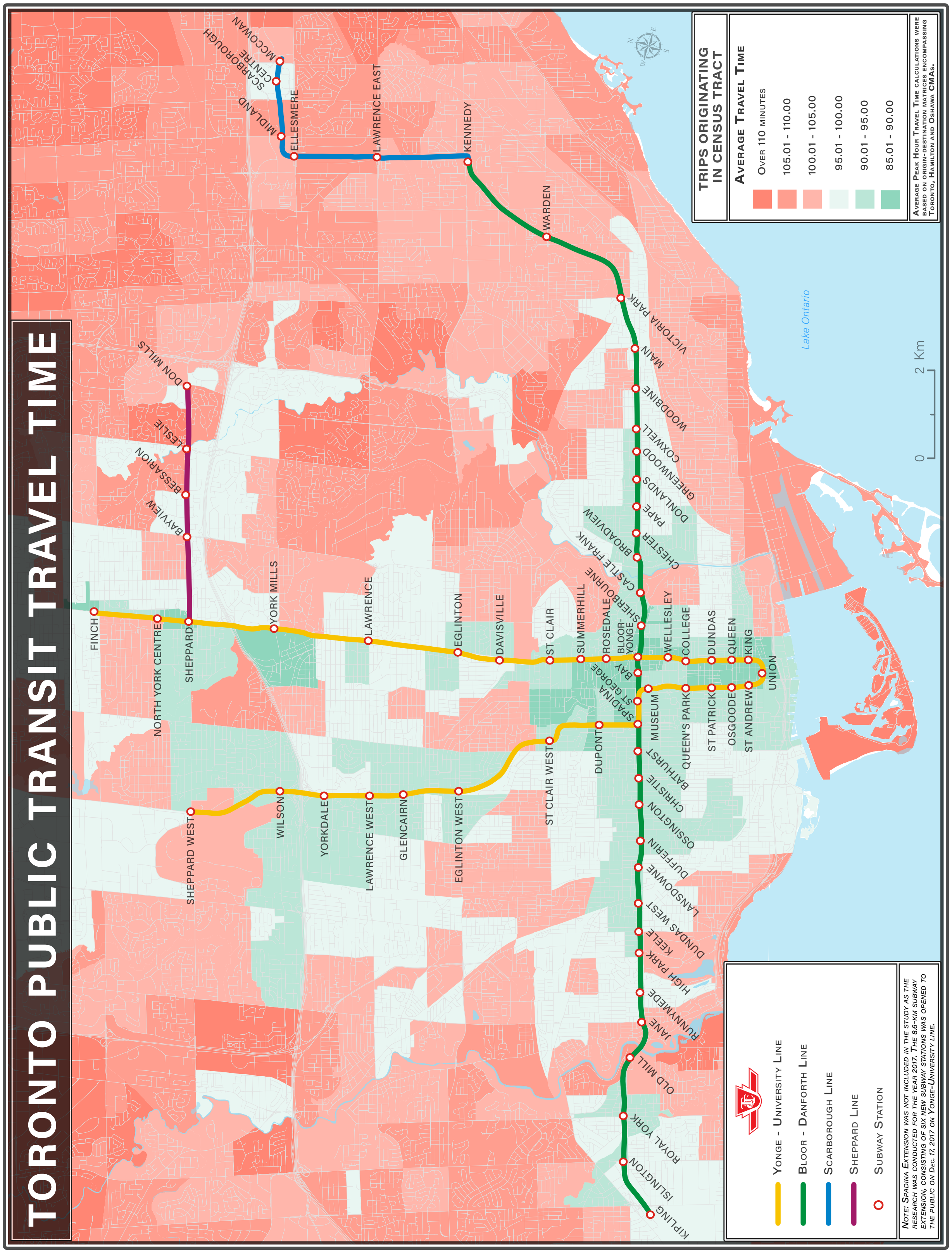


Figure A-1: Toronto Public Transit Travel Time – Trips Originating in Census Tract

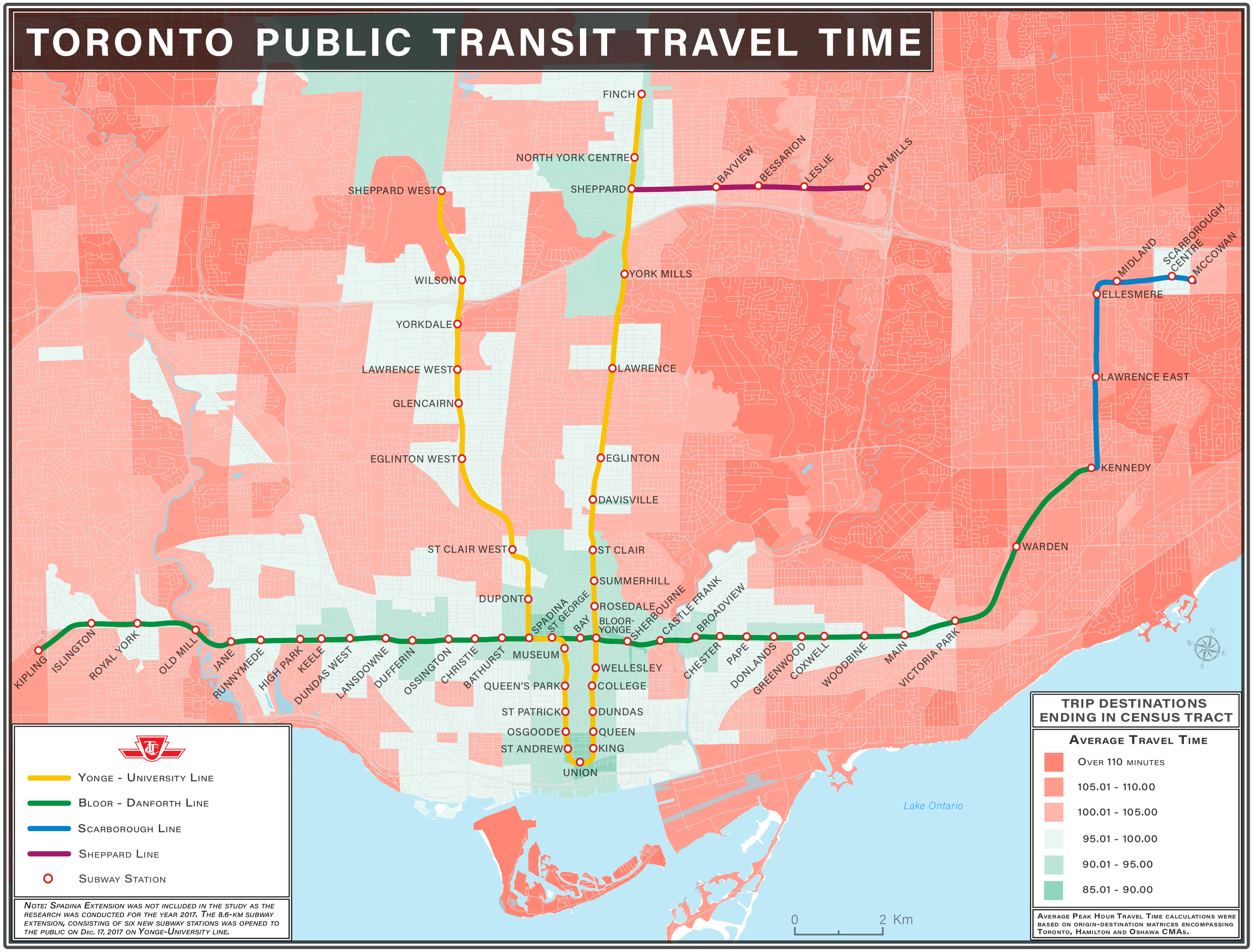


Figure A-2: Toronto Public Transit Travel Time – Trip Destinations Ending in Census Tract

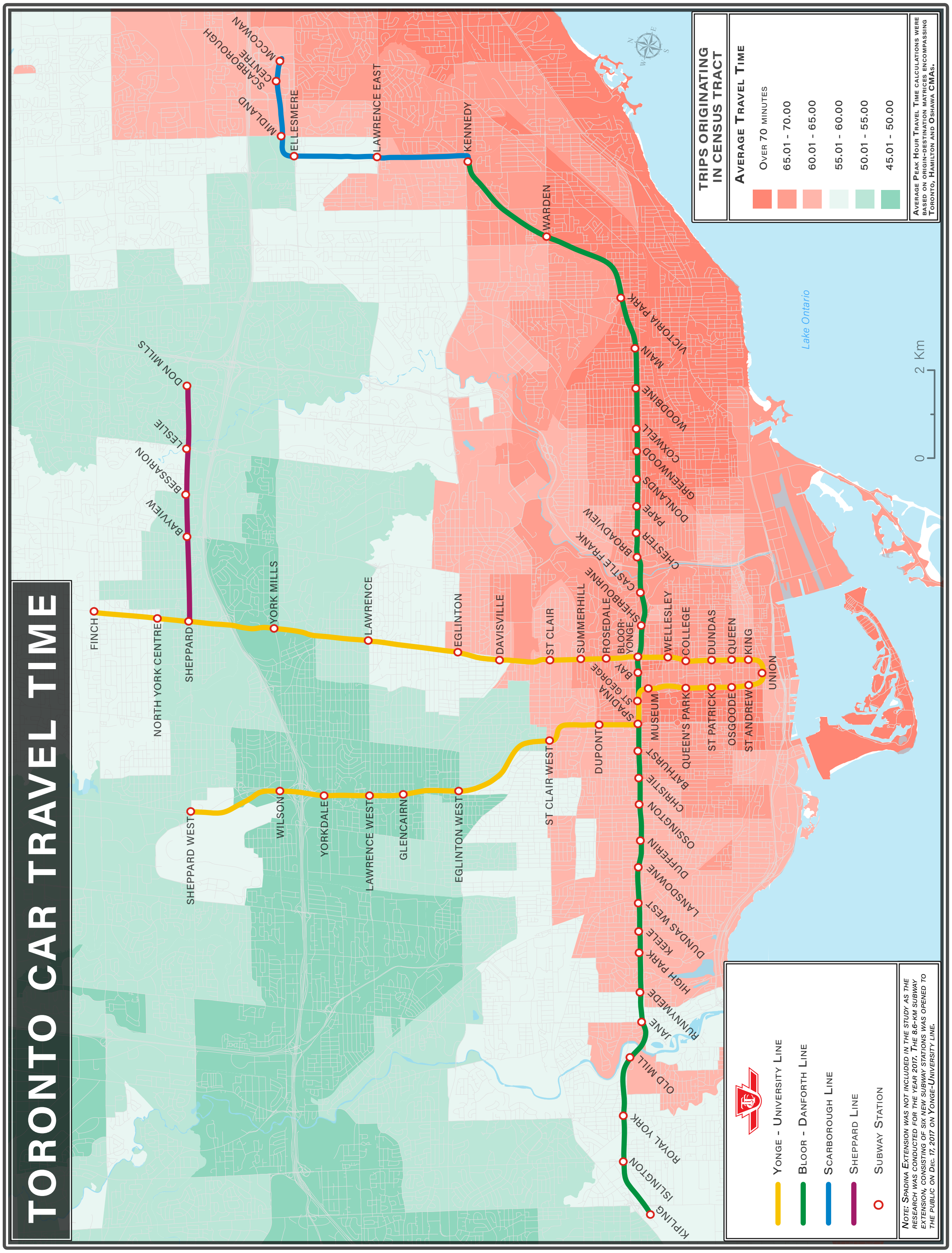


Figure A-3: Toronto Car Travel Time – Trips Originating in Census Tract

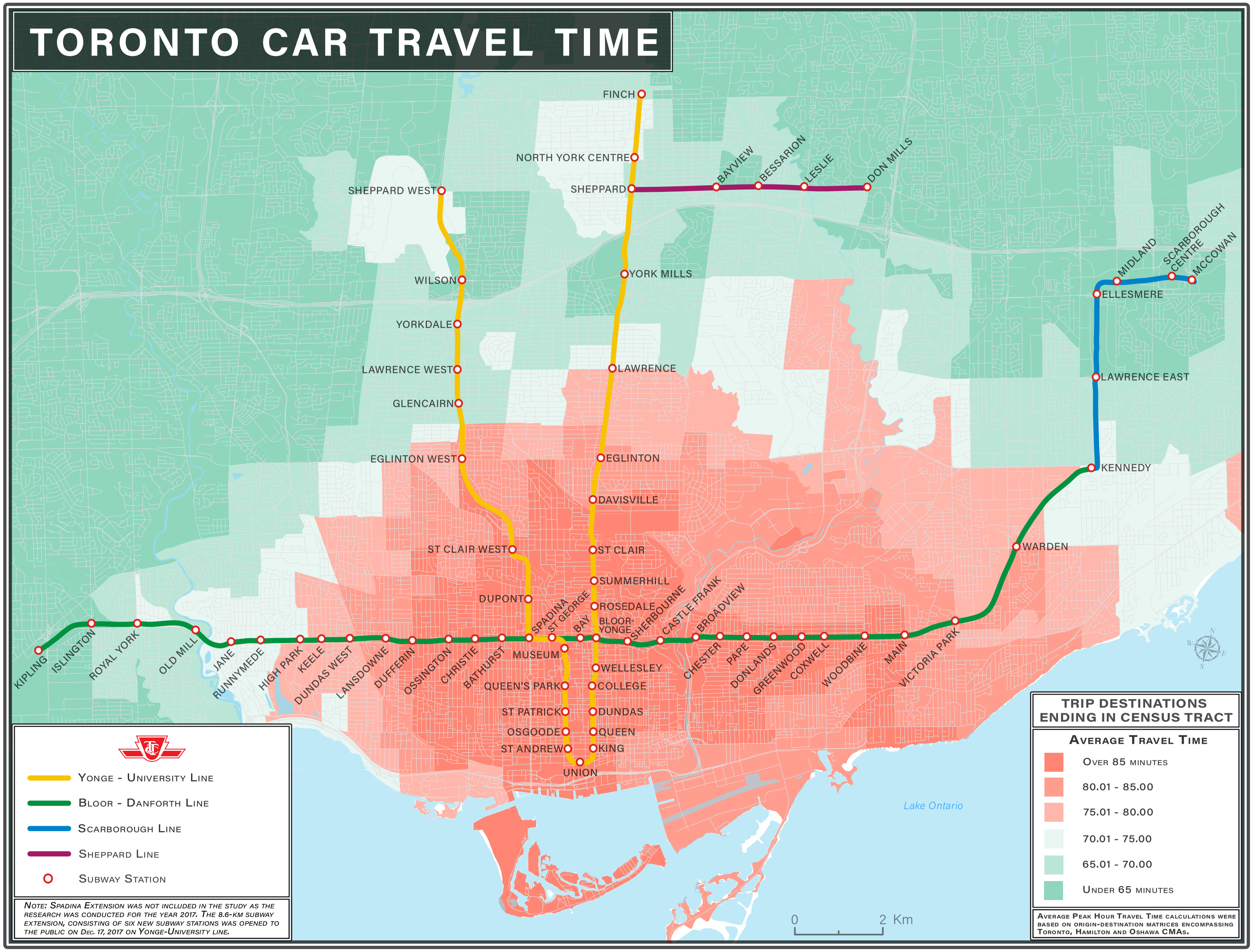


Figure A-4: Toronto Car Travel Time – Trip Destinations Ending in Census Tract

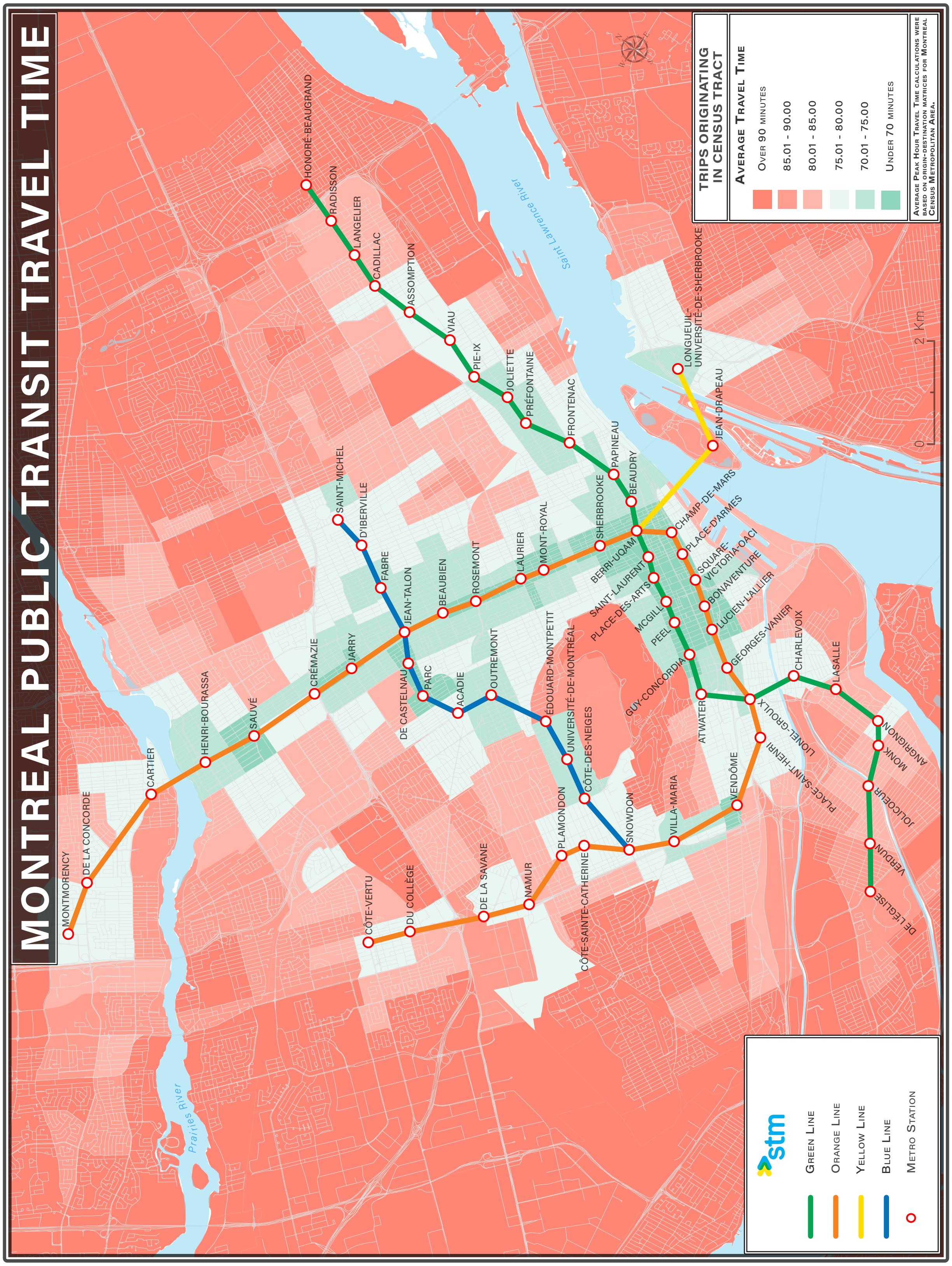


Figure A-5: Montreal Public Transit Travel Time – Trips Originating in Census Tract

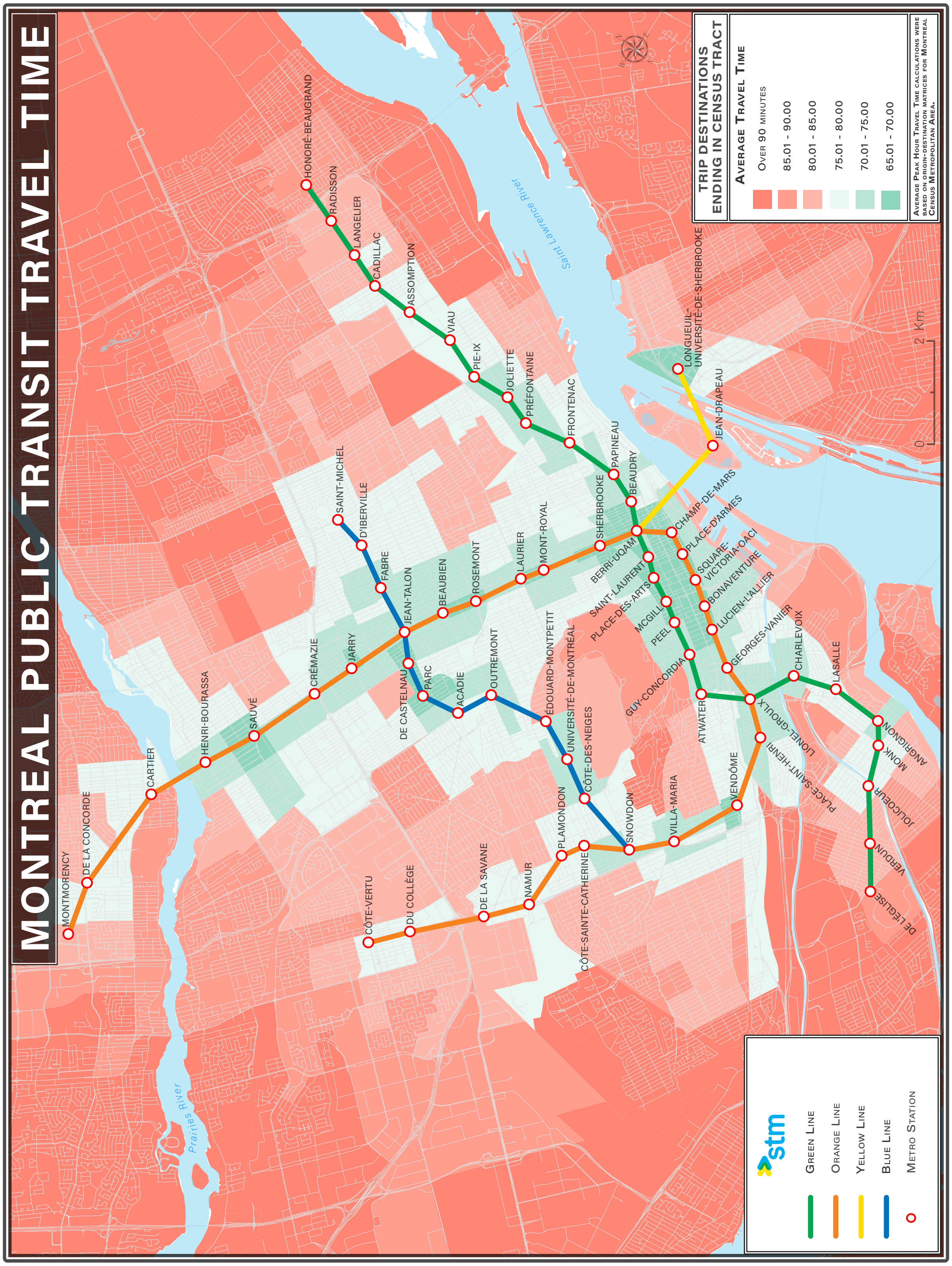


Figure A-6: Montreal Public Transit Travel Time – Trip Destinations Ending in Census Tract

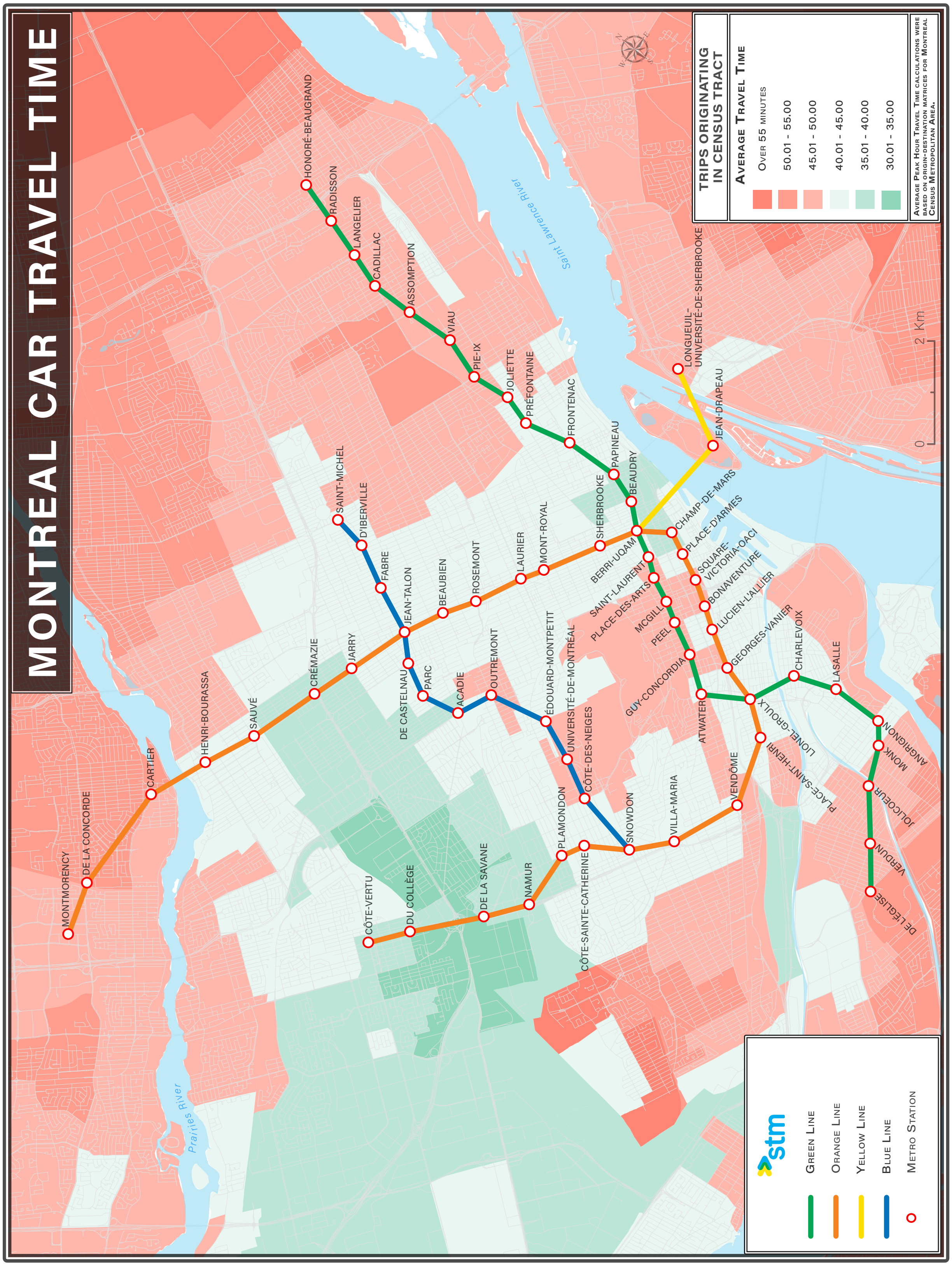


Figure A-7: Montreal Car Travel Time – Trips Originating in Census Tract

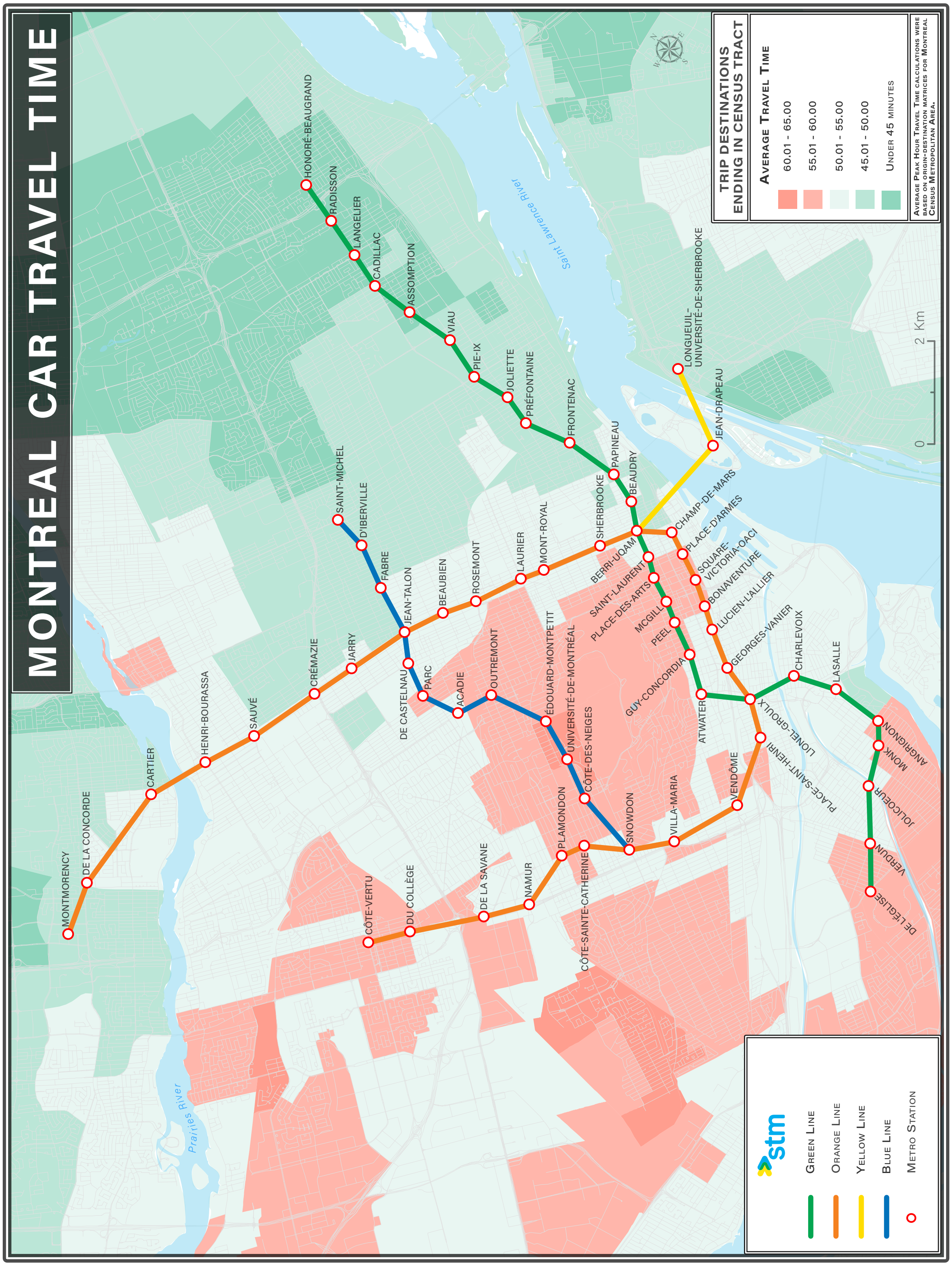


Figure A-8: Montreal Car Travel Time – Trip Destinations Ending in Census Tract

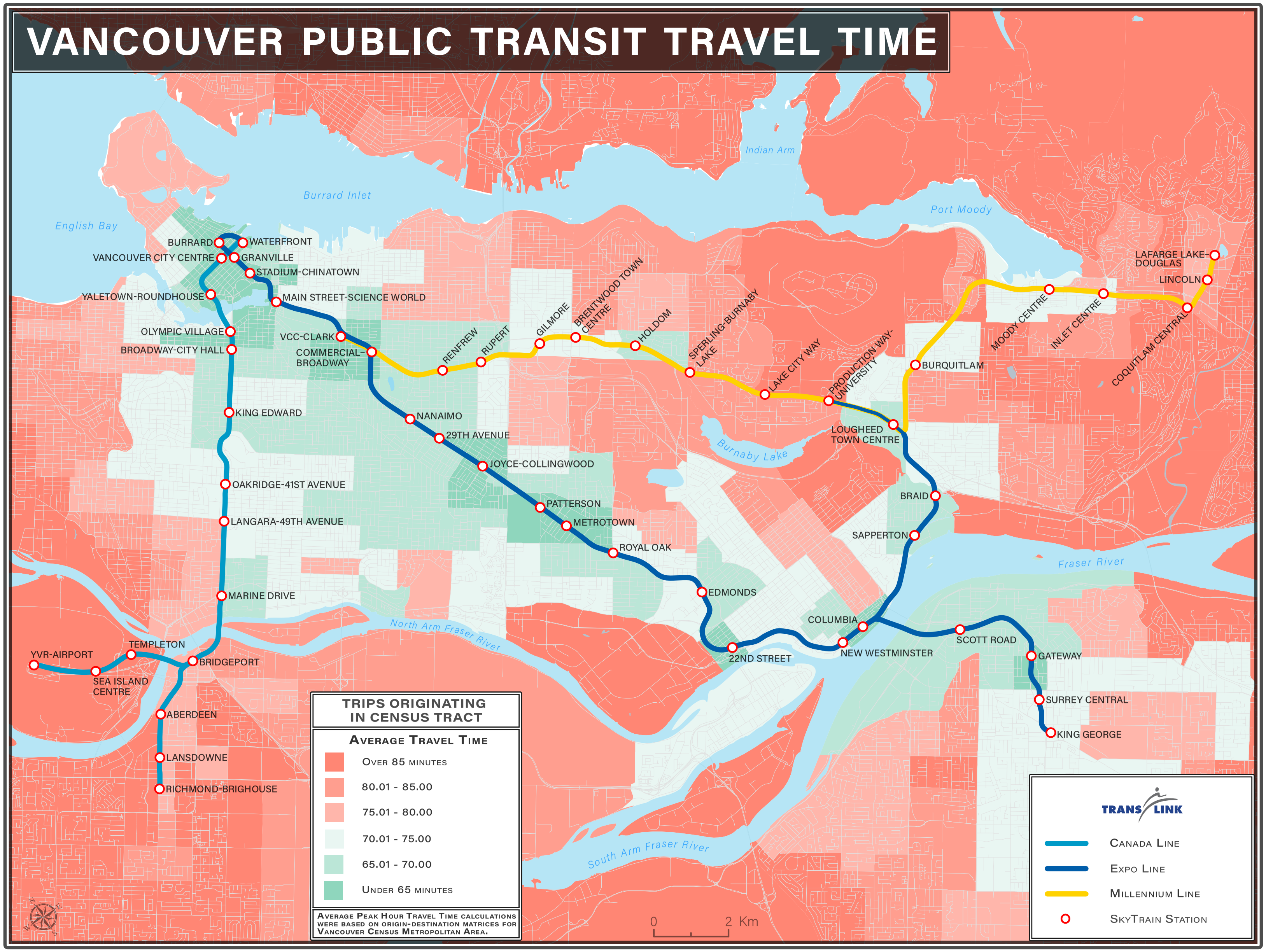


Figure A-9: Vancouver Public Transit Travel Time – Trips Originating in Census Tract

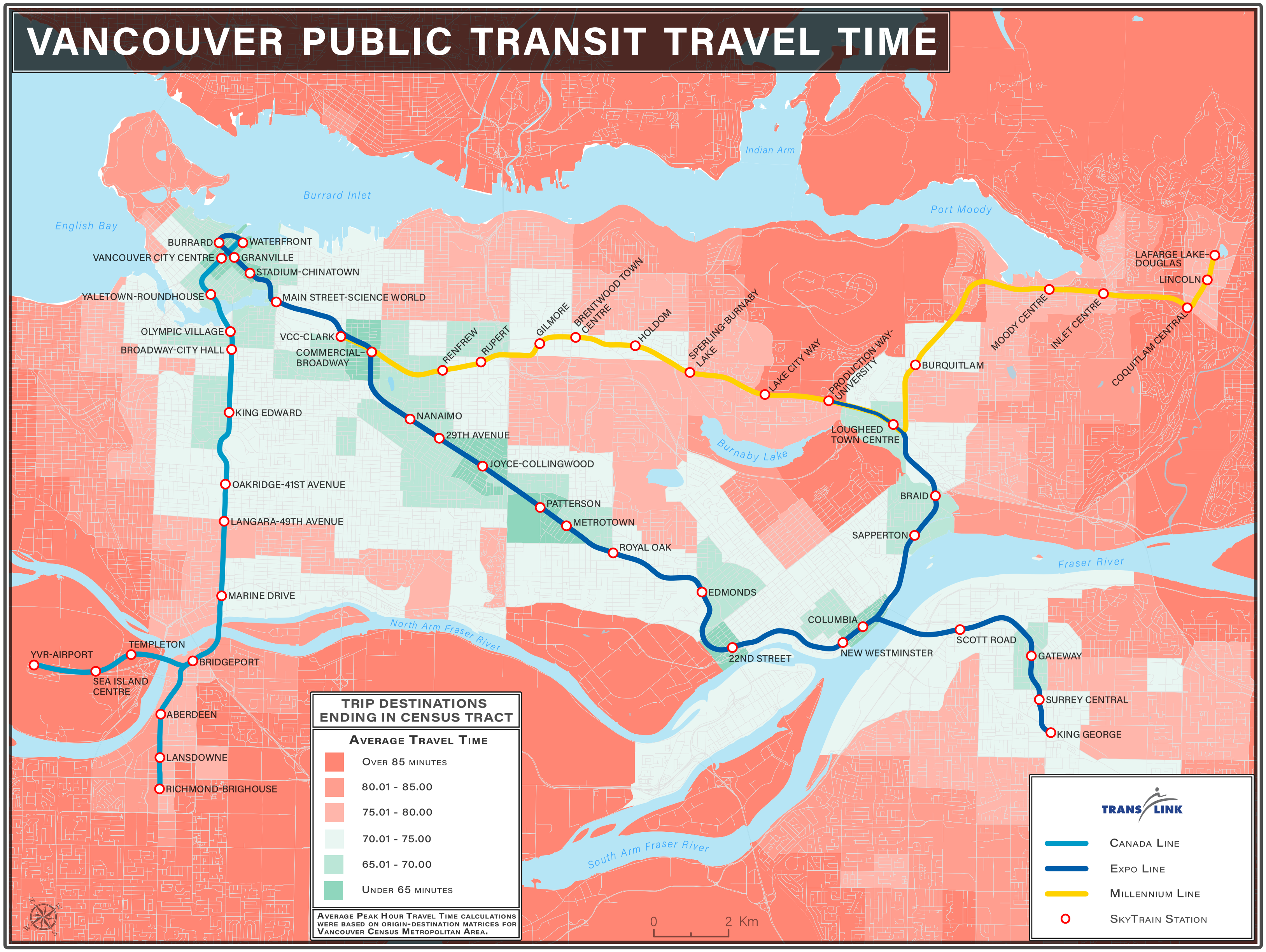


Figure A-10: Vancouver Public Transit Travel Time – Trip Destinations Ending in Census Tract

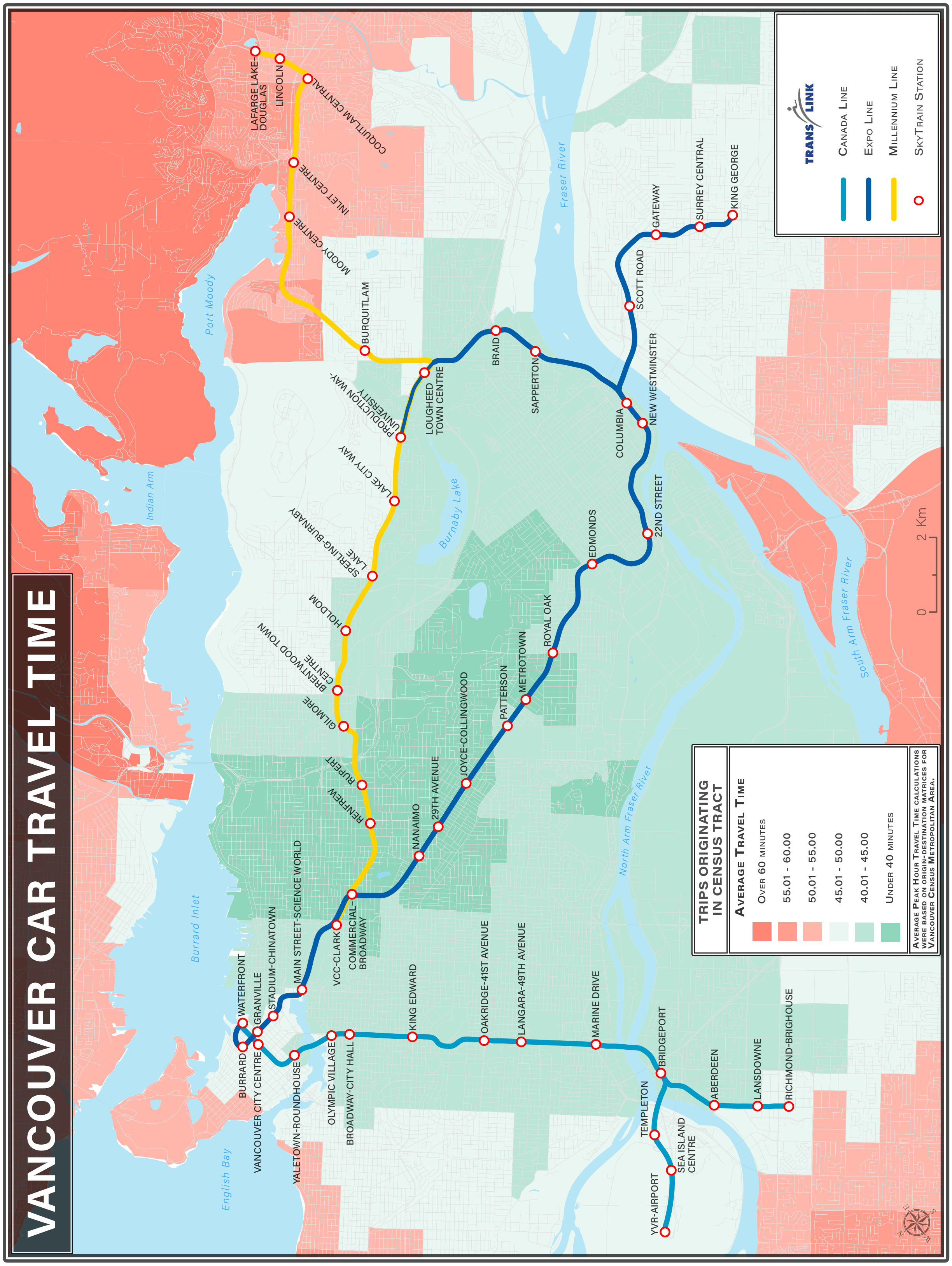


Figure A-11: Vancouver Car Travel Time – Trips Originating in Census Tract

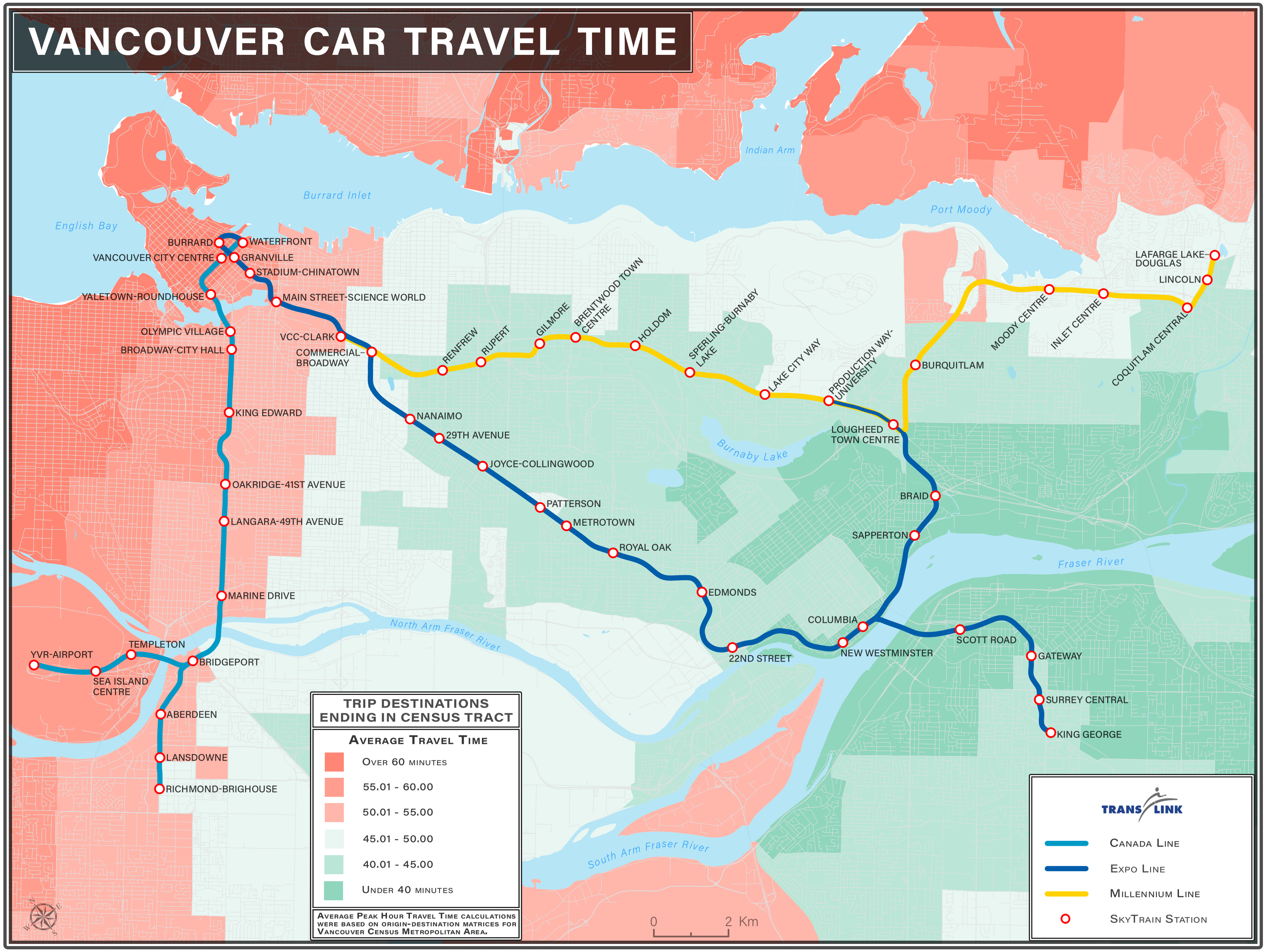


Figure A-12: Vancouver Car Travel Time – Trip Destinations Ending in Census Tract

APPENDIX B

Toronto Regression Models

Table B-1: Toronto Regression Model for Public Transit – Trips less than 10.01 km

Toronto Transit Travel Time (< 10.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-5.892***			
	(0.082)			
Destination 400m		-5.516***		
		(0.083)		
Origin/Destination 400m			-9.558***	
			(0.116)	
Origin/Destination 800m				-8.446***
				(0.094)
Constant	39.333***	39.241***	38.878***	39.305***
	(0.040)	(0.040)	(0.037)	(0.038)
Observations	124,998	124,998	124,998	124,998
R2	0.039	0.034	0.051	0.061
Adjusted R2	0.039	0.034	0.051	0.061
Residual Std. Error (df = 124996)	12.450	12.482	12.372	12.310
F Statistic (df = 1; 124996)	5,111.496***	4,452.157***	6,746.814***	8,079.906***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-2: Toronto Regression Model for Auto Travel Time (Peak Hour) – Trips less than 10.01 km

Auto Travel Time Congested (< 10.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	4.591***			
	(0.068)			
Destination 400m		5.933***		
		(0.068)		
Origin/Destination 400m			3.646***	
			(0.098)	
Origin/Destination 800m				3.964***
				(0.079)
Constant	21.017***	20.696***	21.753***	21.469***
	(0.034)	(0.033)	(0.031)	(0.032)
Observations	124,998	124,998	124,998	124,998
R2	0.035	0.058	0.011	0.020
Adjusted R2	0.035	0.058	0.011	0.020
Residual Std. Error (df = 124996)	10.330	10.204	10.457	10.411
F Statistic (df = 1; 124996)	4,508.175***	7,707.503***	1,374.651***	2,487.979***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-3: Toronto Regression Model Auto Travel Time (Off-Peak Hour) – Trips less than 10.01 km

Auto Travel Time (< 10.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin_400m	2.488***			
	(0.035)			
Destination_400m		2.485***		
		(0.035)		
Origin/Destination 400m			1.647***	
			(0.050)	
Origin/Destination 800m				1.817***
				(0.041)
Constant	13.022***	13.024***	13.455***	13.322***
	(0.017)	(0.017)	(0.016)	(0.016)
Observations	124,998	124,998	124,998	124,998
R2	0.039	0.039	0.008	0.016
Adjusted R2	0.039	0.039	0.008	0.016
Residual Std. Error (df = 124996)	5.268	5.269	5.352	5.332
F Statistic (df = 1; 124996)	5,090.260***	5,071.426***	1,070.089***	1,993.996***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-4: Toronto Regression Model for Public Transit – Trips less than 15.01 km

Transit Travel Time (< 15.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-8.114***			
	(0.079)			
Destination 400m		-7.434***		
		(0.079)		
Origin/Destination 400m			-12.280***	
			(0.119)	
Origin/Destination 800m				-11.394***
				(0.095)
Constant	48.182***	48.037***	47.382***	47.932***
	(0.038)	(0.038)	(0.035)	(0.036)
Observations	226,589	226,589	226,589	226,589
R2	0.044	0.037	0.045	0.060
Adjusted R2	0.044	0.037	0.045	0.060
Residual Std. Error (df = 226587)	15.832	15.889	15.826	15.703
F Statistic (df = 1; 226587)	10,456.620***	8,748.840***	10,626.520***	14,361.230***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-5: Toronto Regression Model for Auto Travel Time (Peak Hour) – Trips less than 15.01 km

Auto Travel Time Congested (< 15.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	5.502***			
	(0.071)			
Destination 400m		8.119***		
		(0.070)		
Origin/Destination 400m			5.012***	
			(0.107)	
Origin/Destination 800m				5.081***
				(0.086)
Constant	28.284***	27.679***	29.108***	28.824***
	(0.034)	(0.033)	(0.031)	(0.032)
Observations	226,589	226,589	226,589	226,589
R2	0.026	0.057	0.010	0.015
Adjusted R2	0.026	0.057	0.010	0.015
Residual Std. Error (df = 226587)	14.126	13.901	14.244	14.204
F Statistic (df = 1; 226587)	6,039.923***	13,632.440***	2,185.344***	3,490.255***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-6: Toronto Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 15.01 km

Auto Travel Time (< 15.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	2.772***			
	(0.033)			
Destination 400m		2.826***		
		(0.033)		
Origin/Destination 400m			1.911***	
			(0.050)	
Origin/Destination 800m				1.997***
				(0.040)
Constant	16.433***	16.417***	16.901***	16.784***
	(0.016)	(0.016)	(0.015)	(0.015)
Observations	226,589	226,589	226,589	226,589
R2	0.030	0.031	0.006	0.011
Adjusted R2	0.030	0.031	0.006	0.011
Residual Std. Error (df = 226587)	6.590	6.586	6.670	6.656
F Statistic (df = 1; 226587)	7,043.402***	7,355.963***	1,448.471***	2,454.877***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-7: Toronto Regression Model for Public Transit – Trips less than 20.01 km

Transit Travel Time (< 20.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-10.646*** (0.082)			
Destination 400m		-9.641*** (0.082)		
Origin/Destination 400m			-16.050*** (0.130)	
Origin/Destination 800m				-15.133*** (0.103)
Constant	56.057*** (0.038)	55.867*** (0.038)	54.937*** (0.035)	55.588*** (0.036)
Observations	338,818	338,818	338,818	338,818
R2	0.047	0.039	0.043	0.060
Adjusted R2	0.047	0.039	0.043	0.060
Residual Std. Error (df = 338816)	19.588	19.672	19.634	19.459
F Statistic (df = 1; 338816)	16,836.490***	13,809.160***	15,166.230***	21,570.780***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-8: Toronto Regression Model for Auto Travel Time (Peak Hour) – Trips less than 20.01 km

Auto Travel Time Congested (< 20.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	5.480*** (0.069)			
Destination 400m		10.036*** (0.068)		
Origin/Destination 400m			4.788*** (0.111)	
Origin/Destination 800m				4.917*** (0.088)
Constant	33.629*** (0.032)	32.628*** (0.031)	34.456*** (0.030)	34.214*** (0.030)
Observations	338,818	338,818	338,818	338,818
R2	0.018	0.061	0.006	0.009
Adjusted R2	0.018	0.061	0.005	0.009
Residual Std. Error (df = 338816)	16.556	16.189	16.662	16.632
F Statistic (df = 1; 338816)	6,245.113***	22,095.670***	1,874.194***	3,117.799***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-9: Toronto Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 20.01 km

Auto Travel Time (< 20.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	2.619*** (0.030)			
Destination 400m		2.928*** (0.030)		
Origin/Destination 400m			1.512*** (0.048)	
Origin/Destination 800m				1.553*** (0.038)
Constant	18.760*** (0.014)	18.687*** (0.014)	19.212*** (0.013)	19.135*** (0.013)
Observations	338,818	338,818	338,818	338,818
R2	0.022	0.027	0.003	0.005
Adjusted R2	0.022	0.027	0.003	0.005
Residual Std. Error (df = 338816)	7.205	7.184	7.274	7.267
F Statistic (df = 1; 338816)	7,533.551***	9,548.206***	980.360***	1,628.752***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Montreal Regression Models

Table B-10: Montreal Regression Model for Public Transit – Trips less than 10.01 km

Transit Travel Time (< 10.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-8.578***			
	(0.077)			
Destination 400m		-8.331***		
		(0.077)		
Origin/Destination 400m			-11.244***	
			(0.091)	
Origin/Destination 800m				-10.983***
				(0.075)
Constant	39.343***	39.264***	38.183***	40.073***
	(0.050)	(0.050)	(0.042)	(0.047)
Observations	122,200	122,200	122,200	122,200
R2	0.093	0.088	0.112	0.150
Adjusted R2	0.093	0.088	0.112	0.150
Residual Std. Error (df = 122198)	13.223	13.260	13.086	12.805
F Statistic (df = 1; 122198)	12,531.180***	11,777.860***	15,364.550***	21,484.710***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-11: Montreal Regression Model for Auto Travel Time (Peak Hour) – Trips less than 10.01 km

Auto Travel Time Congested (< 10.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	1.260***			
	(0.062)			
Destination 400m		3.186***		
		(0.061)		
Origin/Destination 400m			0.751***	
			(0.074)	
Origin/Destination 800m				1.077***
				(0.063)
Constant	24.411***	23.592***	24.778***	24.516***
	(0.040)	(0.040)	(0.035)	(0.039)
Observations	122,200	122,200	122,200	122,200
R2	0.003	0.022	0.001	0.002
Adjusted R2	0.003	0.022	0.001	0.002
Residual Std. Error (df = 122198)	10.716	10.618	10.730	10.721
F Statistic (df = 1; 122198)	411.867***	2,686.288***	102.031***	294.811***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-12: Montreal Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 10.01 km

Auto Travel Time (< 10.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	0.809***			
	(0.033)			
Destination 400m		0.999***		
		(0.033)		
Origin/Destination 400m			0.200***	
			(0.040)	
Origin/Destination 800m				0.314***
				(0.034)
Constant	15.202***	15.119***	15.499***	15.419***
	(0.022)	(0.022)	(0.019)	(0.021)
Observations	122,200	122,200	122,200	122,200
R2	0.005	0.007	0.0002	0.001
Adjusted R2	0.005	0.007	0.0002	0.001
Residual Std. Error (df = 122198)	5.738	5.731	5.752	5.750
F Statistic (df = 1; 122198)	592.340***	906.499***	25.074***	86.962***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-13: Montreal Regression for Model Public Transit – Trips less than 15.01 km

Transit Travel Time (< 15.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-12.212*** (0.083)			
Destination 400m		-12.183*** (0.082)		
Origin/Destination 400m			-17.137*** (0.107)	
Origin/Destination 800m				-16.902*** (0.083)
Constant	48.521*** (0.051)	48.590*** (0.051)	46.745*** (0.043)	49.127*** (0.046)
Observations	213,164	213,164	213,164	213,164
R2	0.093	0.093	0.108	0.162
Adjusted R2	0.093	0.093	0.108	0.162
Residual Std. Error (df = 213162)	18.491	18.489	18.339	17.775
F Statistic (df = 1; 213162)	21,873.620***	21,919.690***	25,792.900***	41,185.120***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-14: Montreal Regression Model for Auto Travel Time (Peak Hour) – Trips less than 15.01 km

Auto Travel Time Congested (< 15.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	-0.574*** (0.059)			
Destination 400m		3.477*** (0.058)		
Origin/Destination 400m			-1.786*** (0.077)	
Origin/Destination 800m				-1.566*** (0.062)
Constant	31.450*** (0.036)	29.893*** (0.036)	31.529*** (0.031)	31.717*** (0.034)
Observations	213,164	213,164	213,164	213,164
R2	0.0004	0.016	0.003	0.003
Adjusted R2	0.0004	0.016	0.003	0.003
Residual Std. Error (df = 213162)	13.211	13.106	13.198	13.195
F Statistic (df = 1; 213162)	94.529***	3,552.847***	540.811***	641.557***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-15: Montreal Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 15.01 km

Auto Travel Time (< 15.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	0.177*** (0.030)			
Destination 400m		0.598*** (0.029)		
Origin/Destination 400m			-1.132*** (0.038)	
Origin/Destination 800m				-1.066*** (0.031)
Constant	18.484*** (0.018)	18.320*** (0.018)	18.739*** (0.016)	18.881*** (0.017)
Observations	213,164	213,164	213,164	213,164
R2	0.0002	0.002	0.004	0.006
Adjusted R2	0.0002	0.002	0.004	0.006
Residual Std. Error (df = 213162)	6.607	6.601	6.594	6.589
F Statistic (df = 1; 213162)	36.023***	414.161***	870.063***	1,193.097***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-16: Montreal Regression Model for Public Transit – Trips less than 20.01 km

Transit Travel Time (< 20.01 km) / Peak Hour (8:00 AM)

	Dependent variable: Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-15.544*** (0.092)			
Destination 400m		-16.207*** (0.092)		
Origin/Destination 400m			-23.697*** (0.131)	
Origin/Destination 800m				-23.313*** (0.099)
Constant	57.089*** (0.054)	57.407*** (0.054)	54.825*** (0.046)	57.421*** (0.048)
Observations	312,675	312,675	312,675	312,675
R2	0.083	0.091	0.095	0.152
Adjusted R2	0.083	0.091	0.095	0.152
Residual Std. Error (df = 312673)	24.456	24.349	24.294	23.518
F Statistic (df = 1; 312673)	28,275.210***	31,261.760***	32,832.070***	56,005.130***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-17: Montreal Regression Model for Auto Travel Time (Peak Hour) – Trips less than 20.01 km

Auto Travel Time Congested (< 20.01 km) / Peak Hour

	Dependent variable: Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	-2.147*** (0.055)			
Destination 400m		3.427*** (0.055)		
Origin/Destination 400m			-4.313*** (0.078)	
Origin/Destination 800m				-4.109*** (0.061)
Constant	36.333*** (0.032)	34.427*** (0.032)	36.151*** (0.028)	36.592*** (0.030)
Observations	312,675	312,675	312,675	312,675
R2	0.005	0.012	0.010	0.014
Adjusted R2	0.005	0.012	0.010	0.014
Residual Std. Error (df = 312673)	14.549	14.493	14.514	14.479
F Statistic (df = 1; 312673)	1,524.018***	3,945.784***	3,047.325***	4,589.540***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-18: Montreal Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 20.01 km

Auto Travel Time (< 20.01 km) / Off-Peak Hour

	Dependent variable: Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-0.429*** (0.026)			
Destination 400m		0.031 (0.026)		
Origin/Destination 400m			-2.579*** (0.037)	
Origin/Destination 800m				-2.558*** (0.029)
Constant	20.824*** (0.015)	20.668*** (0.015)	21.004*** (0.013)	21.292*** (0.014)
Observations	312,675	312,675	312,675	312,675
R2	0.001	0.00000	0.015	0.025
Adjusted R2	0.001	0.00000	0.015	0.025
Residual Std. Error (df = 312673)	6.964	6.967	6.914	6.881
F Statistic (df = 1; 312673)	265.951***	1.385	4,802.807***	7,877.297***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Vancouver Regression Models

Table B-19: Vancouver Regression Model for Public Transit – Trips less than 10.01 km

Transit Travel Time (< 10.01 km) / Peak Hour (8:00 AM)

	Dependent variable: Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-5.334***			
	(0.191)			
Destination 400m		-5.396***		
		(0.191)		
Origin/Destination 400m			-8.390***	
			(0.273)	
Origin/Destination 800m				-7.425***
				(0.226)
Constant	38.688***	38.705***	38.081***	38.459***
	(0.104)	(0.103)	(0.092)	(0.096)
Observations	29,285	29,285	29,285	29,285
R2	0.026	0.026	0.031	0.036
Adjusted R2	0.026	0.026	0.031	0.036
Residual Std. Error (df = 29283)	14.897	14.893	14.857	14.822
F Statistic (df = 1; 29283)	777.362***	795.641***	941.475***	1,082.526***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-20: Vancouver Regression Model for Auto Travel Time (Peak Hour) – Trips less than 10.01 km

Auto Travel Time Congested (< 10.01 km) / Peak Hour

	Dependent variable: Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	2.147***			
	(0.110)			
Destination 400m		2.390***		
		(0.110)		
Origin/Destination 400m			1.254***	
			(0.159)	
Origin/Destination 800m				1.000***
				(0.132)
Constant	17.799***	17.728***	18.285***	18.248***
	(0.060)	(0.060)	(0.054)	(0.056)
Observations	29,285	29,285	29,285	29,285
R2	0.013	0.016	0.002	0.002
Adjusted R2	0.013	0.016	0.002	0.002
Residual Std. Error (df = 29283)	8.603	8.589	8.649	8.649
F Statistic (df = 1; 29283)	377.640***	469.374***	62.106***	57.650***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-21: Vancouver Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 10.01 km

Auto Travel Time (< 10.01 km) / Off-Peak Hour

	Dependent variable: Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	0.895***			
	(0.063)			
Destination 400m		0.811***		
		(0.064)		
Origin/Destination 400m			0.120	
			(0.091)	
Origin/Destination 800m				0.006
				(0.076)
Constant	12.225***	12.250***	12.474***	12.486***
	(0.034)	(0.034)	(0.031)	(0.032)
Observations	29,285	29,285	29,285	29,285
R2	0.007	0.006	0.0001	0.00000
Adjusted R2	0.007	0.006	0.00003	-0.00003
Residual Std. Error (df = 29283)	4.943	4.946	4.960	4.960
F Statistic (df = 1; 29283)	198.945***	162.985***	1.741	0.006
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-22: Vancouver Regression Model for Public Transit – Trips less than 15.01 km

Transit Travel Time (< 15.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-8.822*** (0.190)			
Destination 400m		-8.808*** (0.190)		
Origin/Destination 400m			-13.962*** (0.292)	
Origin/Destination 800m				-12.319*** (0.234)
Constant	49.414*** (0.099)	49.402*** (0.099)	48.294*** (0.089)	48.888*** (0.091)
Observations	53,938	53,938	53,938	53,938
R2	0.039	0.038	0.041	0.049
Adjusted R2	0.039	0.038	0.041	0.049
Residual Std. Error (df = 53936)	19.611	19.613	19.589	19.504
F Statistic (df = 1; 53936)	2,163.817***	2,151.551***	2,287.578***	2,779.549***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-23: Vancouver Regression Model for Auto Travel Time (Peak Hour) – Trips less than 15.01 km

Auto Travel Time Congested (< 15.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	1.505*** (0.114)			
Destination 400m		1.960*** (0.114)		
Origin/Destination 400m			-0.477*** (0.176)	
Origin/Destination 800m				-0.134 (0.141)
Constant	25.045*** (0.059)	24.923*** (0.059)	25.499*** (0.053)	25.476*** (0.055)
Observations	53,938	53,938	53,938	53,938
R2	0.003	0.005	0.0001	0.00002
Adjusted R2	0.003	0.005	0.0001	-0.00000
Residual Std. Error (df = 53936)	11.772	11.759	11.791	11.791
F Statistic (df = 1; 53936)	174.731***	296.360***	7.355***	0.896
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-24: Vancouver Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 15.01 km

Auto Travel Time (< 15.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	0.365*** (0.063)			
Destination 400m		0.322*** (0.063)		
Origin/Destination 400m			-0.907*** (0.096)	
Origin/Destination 800m				-0.704*** (0.077)
Constant	16.332*** (0.033)	16.344*** (0.033)	16.514*** (0.029)	16.538*** (0.030)
Observations	53,938	53,938	53,938	53,938
R2	0.001	0.0005	0.002	0.002
Adjusted R2	0.001	0.0005	0.002	0.002
Residual Std. Error (df = 53936)	6.469	6.469	6.465	6.466
F Statistic (df = 1; 53936)	33.992***	26.360***	88.530***	82.551***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-25: Vancouver Regression Model for Public Transit – Trips less than 20.01 km

Transit Travel Time (< 20.01 km) / Peak Hour (8:00 AM)

	Dependent variable:			
	Transit Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-11.580***			
	(0.189)			
Destination 400m		-11.463***		
		(0.189)		
Origin/Destination 400m			-18.573***	
			(0.307)	
Origin/Destination 800m				-16.615***
				(0.240)
Constant	58.397***	58.349***	56.880***	57.667***
	(0.096)	(0.096)	(0.086)	(0.088)
Observations	81,280	81,280	81,280	81,280
R2	0.044	0.043	0.043	0.056
Adjusted R2	0.044	0.043	0.043	0.056
Residual Std. Error (df = 81278)	23.489	23.502	23.503	23.347
F Statistic (df = 1; 81278)	3,770.568***	3,675.978***	3,670.902***	4,809.181***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-26: Vancouver Regression Model for Auto Travel Time (Peak Hour) – Trips less than 20.01 km

Auto Travel Time Congested (< 20.01 km) / Peak Hour

	Dependent variable:			
	Car Travel Time Congested			
	(1)	(2)	(3)	(4)
Origin 400m	0.597***			
	(0.111)			
Destination 400m		1.438***		
		(0.111)		
Origin/Destination 400m			-2.085***	
			(0.180)	
Origin/Destination 800m				-1.356***
				(0.142)
Constant	30.784***	30.570***	31.101***	31.120***
	(0.056)	(0.056)	(0.050)	(0.052)
Observations	81,280	81,280	81,280	81,280
R2	0.0004	0.002	0.002	0.001
Adjusted R2	0.0003	0.002	0.002	0.001
Residual Std. Error (df = 81278)	13.805	13.794	13.796	13.800
F Statistic (df = 1; 81278)	28.979***	168.044***	134.224***	91.639***
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table B-27: Vancouver Regression Model for Auto Travel Time (Off-Peak Hour) – Trips less than 20.01 km

Auto Travel Time (< 20.01 km) / Off-Peak Hour

	Dependent variable:			
	Car Travel Time			
	(1)	(2)	(3)	(4)
Origin 400m	-0.251***			
	(0.060)			
Destination 400m		-0.300***		
		(0.060)		
Origin/Destination 400m			-2.008***	
			(0.098)	
Origin/Destination 800m				-1.543***
				(0.077)
Constant	19.629***	19.641***	19.722***	19.772***
	(0.031)	(0.031)	(0.027)	(0.028)
Observations	81,280	81,280	81,280	81,280
R2	0.0002	0.0003	0.005	0.005
Adjusted R2	0.0002	0.0003	0.005	0.005
Residual Std. Error (df = 81278)	7.510	7.510	7.492	7.493
F Statistic (df = 1; 81278)	17.345***	24.639***	422.146***	402.618***
Note:	*p<0.1; **p<0.05; ***p<0.01			

REFERENCES

Alarcon, F., Cho, Y.J., Degerstrom, A., Hartle, A., & Sherlock, R. (2018). *The TOD Evaluation Method Evaluating TOD on Station Area and Corridor Scales.* Retrieved from the University of Minnesota Digital Conservancy.

American Public Transportation Association. (2017). *Public Transportation Ridership Report – Second Quarter, 2017.* Retrieved from https://www.apta.com/wp-content/uploads/Resources/resources/statistics/Documents/Ridership/2017-q2-ridership-APTA.pdf

American Public Transportation Association. (2018). *Public Transportation Ridership Report – Fourth Quarter, 2017.* Retrieved from https://www.apta.com/wp-content/uploads/Resources/resources/statistics/Documents/Ridership/2017-Q4-Ridership-APTA.pdf

Anderson, M.D., & Souleyrette, R.R. (1996) "A geographic information system based transportation forecast model for use in small urbanized areas," *75th TRB Annual Meeting,* Paper. Washington,DC.

Batchelor, B. (2016). *The Effects of Long Commutes and What To Do About Them – An Annotated Bibliography.* Close Commute Systems.

Benenson, I., Martens, K., Rofe, Y., & Kwartler, A. (2011). Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area. *Annals of Regional Science*, *47*(3), 499–515.

Bennardo, M. (2019). *StatsCan study shows Canadian commute times are getting longer - and it's costing us.* Retrieved from https://www.cbc.ca/news/business/statistics-canada-commute-times-study-1.5038796

Bernick, M., & Cervero, R. (1997). *Transit Villages for the 21st Century.* New York: McGraw-Hill.

California Department of Transportation. (2002). *Statewide Transit-Oriented Development Study: Factors for Success in California.* Sacramento: Business, Transportation, and Housing Agency.

Cervero, R. (1993). *Ridership Impacts of Transit-Focused Development in California.* Berkeley: Institute of Urban and Regional Development, University of California, Monograph 45.

Cervero, R. (1996). Mixed land-uses and commuting: evidence from the American Housing Survey. *Transportation Research Part A*, *30*, 361–377.

City of Toronto Open Data. (2018). TTC Subway Shapefiles. Retrieved from https://open.toronto.ca/dataset/ttc-subway-shapefiles/

City of Toronto. (2019). *City of Toronto Report EX9.1: Toronto-Ontario Transit Update.* Retrieved from:http://www.ttc.ca/About_the_TTC/Commission_reports_and_information/Commission_meetings/2019/October_24/Reports/11_City_of_Toronto_Report_EX9_1_Toronto-Ontario_Transit_Upda.pdf

Dachis, B. (2015). *Tackling Traffic: The Economic Cost of Congestion in Metro Vancouver.* C.D. Howe Institute.

Daniels, R., & Mulley, C. (2013). Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use*, *6*(2), 5-20.

De Vos, J., Van Acker, V., & Witlox, F. (2014). The influence of attitudes on transit-oriented development: An explorative analysis. *Transport Policy, 35*, 326–329.

El-Geneidy, A. & Cui, B. (2019). *Origin and destination matrices of travel times and travel distances for Car and Public Transportation for Canadian Census Metropolitan Areas, 2017* [Data set]. Montreal: McGill University.

El-Geneidy, A., Grimsrud, M., Wasfi, R., Tétreault, P., & Surprenant-Legault, J. (2014). New evidence on walking distances to transit stops: Identifying redundancies and gaps using variable service areas. *Transportation*, *41*(1), 193-210.

ESRI. (n.d.). Network analysis workflow: OD cost matrix analysis [webpage]. Retrieved from https://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/od-cost-matrix.htm.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment: A Meta Analysis. *Journal of the American Planning Association, 76*(3), 265-294.

Garreau, Joel. (1992). *Edge City: Life on the New Frontier.* Doubleday & Company, Incorporated.

Gilbert, D. (2016). Montréal Metro. In *The Canadian Encyclopedia.* Retrieved from https://www.thecanadianencyclopedia.ca/en/article/montreal-metro

Google. (n.d.). *GTFS Static Overview*. Retrieved from: https://developers.google.com/transit/gtfs

GTFS. (n.d.-a). *GTFS: Making Public Transit Data Universally Accessible.* Retrieved from: https://gtfs.org/

GTFS. (n.d.-b). *General Transit Feed Specification Reference*. Retrieved from: https://gtfs.org/reference/static/

Guo, J.Y., & Chen, C. (2007). The built environment and travel behavior: making the connection. *Transportation, 35*, 529–533.

Gutiérrez, J., & García-Palomares, J.C. (2008). Distance-measure Impacts on the Calculation of Transport Service Areas Using GIS. *Environment and Planning B*, *35*(3), 480-503.

Gwilliam, K. (1997). *The Value of Time in Economic Evaluation of Transport Projects: Lessons from Recent Research*. World Bank.

Haider, M. (2018). *Public transit is better, but cars are faster.* Retrieved from https://www.theglobeandmail.com/opinion/public-transit-is-better-but-cars-are-faster/article12893839/

Hensher, D. A. (2008). *Handbook of transport geography and spatial systems*. Bingley, UK: Emerald.

Hong Kong Census and Statistics Department. (2018). *Population Estimates.* Available from http://www.censtatd.gov.hk/hkstat/sub/so150.jsp.

Hsiao, S., Lu, J., Sterling, J., & Weatherford, M. (1997). Use of Geographic Information System for Analysis of Transit Pedestrian Access. *Transportation Research Record*, *1604*(1), 50–59.

Infrastructure Canada. (2018). *Building Strong Cities Through Investments in Public Transit.* Retrieved from https://www.infrastructure.gc.ca/plan/ptif-fitc-eng.php

Infrastructure Canada. (2019). *Investing in Canada Plan*. Retrieved from https://www.infrastructure.gc.ca/plan/about-invest-apropos-eng.html

Kimpel, T., Dueker, K., & El-Geneidy, A. (2007). Using GIS to measure the effects of service areas and frequency on passenger boardings at bus stops. *Journal of the Urban and Regional Information Systems Association, 19*(1), 5-11.

Kuby, M., Barranda, A., & Upchurch, C. (2004). Factors influencing light-rail station boardings in the United States. *Transportation Research Part A: Policy and Practice*, *38*(3), 223-247.

Kwoka, G., Boschmann, E., & Goetz, A. (2015). The impact of transit station areas on the travel behaviors of workers in Denver, Colorado. *Transportation Research Part A: Policy and Practice, 80*, 277-287.

Lesack, P. (2019). TransLink Transit GIS Data (V1 Version) [Data file]. TransLink: South Coast British Columbia Transportation Authority. Retrieved from http://hdl.handle.net/11272/10743

Lindsey, M., Schofer, J.L., Durango-Cohen, P., & Gray, K.A. (2010). Relationship between proximity to transit and ridership for journey-to-work trips in Chicago. *Transportation Research Part A, 44*, 697–709.

Lu, Y., Gou, Z., Xiao, Y., Sarkar, C., & Zacharias, J. (2018). Do Transit-Oriented Developments (TODs) and Established Urban Neighborhoods Have Similar Walking Levels in Hong Kong? *International journal of environmental research and public health*, *15*(3), 555.

Lund, H., Cervero, R., & Willson, R. (2004). *Travel Characteristics of Transit-Oriented Development in California.* Statewide Planning Studies, Final Report FTA Section 5313. California Department of Transportation, Sacramento.

Metrolinx. (2008). *The Big Move: Transforming Transportation in the Greater Toronto and Hamilton Area.* Metrolinx, Government of Ontario.

Metz, D. (2008) The Myth of Travel Time Saving. *Transport Reviews, 28*(3), 321-336.

Meyer, M. D., & Institute of Transportation Engineers. (2016). *Transportation Planning Handbook: Vol. Fourth edition*. Wiley.

Ministry of Municipal Affairs and Housing. (2019). *Places to Grow: Growth Plan for the Greater Golden Horseshoe.* Retrieved from:https://files.ontario.ca/mmah-greater-golden-horseshoe-place-to-grow-english-15may2019.pdf

Muley, D., Bunker, J., & Ferreira, L. (2009). Investigation into travel modes of TOD users: impacts of personal and transit characteristics. *International Journal of ITS Research*, *7* (1).

Murray, A.T., & Wu, X. (2003). Accessibility tradeoffs in public transit planning. *Journal of Geographical Systems*, *5*, 93-107.

Nasri, A., & Zhang, L. (2014). The analysis of transit-oriented development (TOD) in Washington, D.C. and Baltimore metropolitan areas. *Transport Policy, 32*, 172-179.

Nasri, A., & Zhang, L. (2019). How Urban Form Characteristics at Both Trip Ends Influence Mode Choice: Evidence from TOD vs. Non-TOD Zones of the Washington, D.C. Metropolitan Area. *Sustainability, MDPI, Open Access Journal*, *11*(12), 1-16.

National Academies of Sciences, Engineering, and Medicine. (2004). *Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects.* Washington, DC: The National Academies Press.

National Academies of Sciences, Engineering, and Medicine. (2008). *Effects of TOD on Housing, Parking, and Travel*. Washington, DC: The National Academies Press.

Neilson, G. & Fowler, W. (1972). Relation between transit ridership and walking distances in a low-density Florida retirement area. *Highway Research Record, 403*, 26–34.

O'Neill, W., Ramsey, D., & Chou, J.(1992). Analysis of transit service areas using geographic information systems. *Transportation Research Record, 1364*, 131–139.

Open Mobility Data. (2019). TTC GTFS. Retrieved from https://transitfeeds.com/p/ttc/33

Parsons Brinckerhoff Quade and Douglas Inc. (1995*). Regional Transit Corridors: The Land Use Connection.* H-1 Project, TCRP, National Research Council, Washington, D.C.

Racca, D. P., & Ratledge, E. (2003). *Factors that affect and/or can alter mode choice.* Newark, Delaware: Delaware Center for Transportation, University of Delaware.

Renne, J. (2005). *Transit-Oriented Development: Measuring Benefits, Analyzing Trends, And Evaluating Policy.* Dissertation, Rutgers State University.

Renne, J., Voorhees, A., Bloustein, E., & Jenks, C. (2005). *Transit-Oriented Development: Developing a strategy to measure success.* NCHRP Project 20-65(5).

Rodrigue, J-P., Comtois, C. and Slack, B. (2013). *The geography of transport systems*. 3rd ed. London and New York: Routhledge.

Salonen, M., & Toivonen, T. (2013). Modelling travel time in urban networks: comparable measures for private car and public transport. *Journal of Transport Geography, 31*, 43–153.

Schlossberg, M., Agrawal, A., Irvin, K., & Bekkouche, V. (2007). *How far, by which route, and why? A spatial analysis of pedestrian preference* (MTI Report 06-06). San Jose, CA: Mineta Transportation Institute & College of Business, San Jose State University.

Shinkle, D. (2012). *Transit-Oriented Development in the States.* National Conference of State Legislatures.

Slavin, H.L. (2008), "The Role of GIS in Land Use and Transport Planning", Hensher, D.A., Button, K.J., Haynes, K.E. & Stopher, P.R. (Ed.) Handbook of Transport Geography and Spatial Systems (Vol. 8), Emerald Group Publishing Limited, pp. 329-356.

Société de transport de Montréal. (n.d.-a). Networks [webpage]. Retrieved from http://www.stm.info/en/info/networks

Société de transport de Montréal. (n.d.-b). Developers [webpage]. Retrieved from http://www.stm.info/en/about/developers

Statistics Canada. (2016a). *Census Tract Boundary File, 2016 Census.* Catalogue no. 92-168-X. Available from: https://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2016-eng.cfm

Statistics Canada. (2016b). *Road Network File, 2016 Census*. Catalogue no. 92-500-X. Available from: https://www12.statcan.gc.ca/census-recensement/2011/geo/RNF-FRR/index-2011-eng.cfm?year=16

Statistics Canada. (2017). *Journey to work: Key results from the 2016 Census.* Component of Statistics Canada catalogue no. 11-001-X. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/171129/dq171129c-eng.pdf

Stringham, M. (1982). "Travel Behavior Associated with Land Uses Adjacent to Rapid Transit Stations," *ITE Journal, 52*(1), 18–22.

Suzuki, H., Cervero, R., & Iuchi, K. (2013). *Transforming cities with transit: Transit and land-use integration for sustainable urban development*. Retrieved from https://ebookcentral-proquest-com.ezproxy.lib.ryerson.ca.

Teodorovic, D., & Janic, M. (2016). *Transportation Engineering: Theory, Practice and Modeling*. Butterworth-Heinemann.

Thomas, R., Pojani, D., Lenferink, S., Bertolini, L., Stead, D., & van der Krabben, E. (2018). Is transitoriented development (TOD) an internationally transferable policy concept? *Regional Studies*, *52*(9), 1201- 1213.

Toronto Transit Commission. (n.d.-a). *About the TTC: Operating Statistics 2017.* Retrieved from https://www.ttc.ca/About_the_TTC/Operating_Statistics/2017/index.jsp

Toronto Transit Commission. (n.d.-b). *Toronto-York Spadina Subway Extension.* Retrieved from https://www.ttc.ca/Spadina/index.jsp#

Translink. (n.d.). Quick Facts [webpage]. Retrieved from https://www.translink.ca/About-Us/Corporate-Overview/Operating Companies/BCRTC/Quick-Facts.aspx

Translink. (2012). *Transit-Oriented Communities Design Guidelines – Creating more livable places around transit in Metro Vancouver.* Retrieved from https://www.translink.ca/~/media/documents/plans_and_projects/transit_oriented_communities/transit_oriented_communities_design_guidelines.ashx

Tsai, Y. (2009). Impacts of self-selection and transit proximity on commute mode choice: evidence from Taipei rapid transit system. *Ann. Reg. Sci., 43*, 1073–1094.

Turner, S., Eisle, W., Benz, R., and Holdener, D. (1998) *Travel Time Data Collection Handbook.* Texas Transportation Institute.

Victoria Transport Policy Institute. (2016). *Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications [Second Edition].* Victoria, BC.

Wales, T. (2008) The Road Less Traveled: TransLink's Improbable Journey from 1999 to 2008. Burnaby, BC: TransLink

Wang, F. & Xu, Y. (2011). Estimating O-D travel time matrix by Google Maps API: implementation, advantages, and implications. *Annals of GIS, 17*, 199-209.

Zamir, K., Nasri, A., Baghaei, B., Mahapatra, S., & Zhang, L. (2014). Effects of Transit-Oriented Development on Trip Generation, Distribution, and Mode Share in Washington, D. C., and Baltimore, Maryland. *Transportation Research Record: Journal of the Transportation Research Board*, *2413*, 45-53.

Zhao, F., Chow, L.-F., Li, M.-T., Ubaka, I., & Gan, A. (2003). Forecasting Transit Walk Accessibility: Regression Model Alternative to Buffer Method. *Transportation Research Record*, *1835*(1), 34–41.