Impacts of Transportation Planning on Economic Development:

The relationship between economic, social, and environmental variables and transit hubs measured through spatial statistics

by

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Abstract

The objective of this research is to identify the rate of change surrounding transit lines in the regions of Montreal, Vancouver, and Toronto. The rate of change is observed through a sustainability lens bringing to light the economic, social and environmental perspective. The shift between once rural to urban settlement had advanced the study of globalization research.

Through the adoption of Canadian census and satellite imaging a 25-year rate of change analysis is performed. A total of seven variables are measured to identify whether a consistent rate of change could be retrieved between the 1981 and 2006 census years: (1) average dwelling value; (2) average number of rooms per dwelling; (3) average gross monthly rent; (4) average household income represent economic variables; (5) population density; (6) average number of persons per household represent social variables; and (7) the removal of green space represents environmental variables.

In the case of Metropolitan Vancouver, data shows a strong relationship between the rates of change in variables over the 25-year period meaning growth and development occurred along transit. In the case of the City of Toronto, data points to moderate development along the selected transit line. In the case of Metropolitan Montreal, no distinct rate of change was observed meaning that transit did not foster urban development growth.

Foreword

This major paper provides a direct role in the fulfilling of my plan of study and overall Master in Environmental Studies program. My plan of study is based on understanding the relation that transportation planning and economic development have in major regional Canadian cities. This research sought to explore these topics through three individual case studies in Vancouver, Toronto, and Montreal. Moreover, a deep understanding of transportation planning and real estate principles were examined at both the quantitative and qualitative level.

My research put a large emphasis on planning and economics to meet two distinct requirements of the Master in Environmental Studies program. The initial requirement focused on planning, specifically transportation planning, as a way to obtain the Ontario Professional Planners Institute (OPPI) recognition. The second requirement is to provide a strong business and environmental focus to obtain the Graduate Diploma in Business and the Environment offered jointly by the Faculty of Environmental Studies and Schulich School of Business.

Table of Contents

List of Figures

List of Tables

Introduction

Objectives

The objective of this research is to identify a rate of change or a degree of change that is attributed to a specified variable from transit development. While this research primarily focuses on the change of economic variables attributed to transportation corridors, social and environmental variables are also observed. Measuring societal and environmental changes are crucial to note as these two frameworks ultimately join to create the triple bottom line theory of sustainability (Svensson et al., 2016).

This section provides a review of smart growth and transit-oriented development, followed by each of the economic, social, and environmental variables measured. Moreover, the overall objectives, hypothesis, assumptions, and methodology are described in this section alongside a brief description of the selected study areas.

How transportation planning influences economic development

Three theories pertaining to economic development and planning are explored in this review: (1) smart growth and its influence on sprawling developments, (2) transit oriented development and its role in transportation planning, and (3) the triple bottom approach aiming to encourage sustainability throughout urban development.

Smart Growth

Smart growth is a contested concept, yet its core principles entail a range of regulatory, financial, and educational practices to coordinate transportation and land use planning (Geller, 2003; Miller and Hoel, 2002). As argued by Cunningham and Cunningham (2012) smart growth aims to produce a variety of mix land use policies and opportunities of urban communities by providing multiple modes of transportation choices. Smart growth plans are generally developed around key objectives: to create a positive image for the community; to promote a liveable downtown; to alleviate poor housing; and to solve environmental pollution. Building on Cunningham and Cunningham (2012), Behan et al. and the U.S Environmental Protection agency (2008; 2015) outline similar distinctions of smart growth. Smart growth is said to be inclusive of mixed use, compact neighbourhoods where a variety of walking and transportation choices are available. Policies of urban residential intensification aim to increase densities and decentralize sprawling communities.

According to Miller and Hoel (2002), smart growth planning encompasses balancing the goal of the individual person to the goal of the community. Within this question, the issues surrounding transportation and land development are explored. Since Post World War II, many municipalities and communities sought to develop low density suburban housing developments where made possible through low density zoning regulations, rising incomes encouraging larger estates, segregation of marginalized communities, technological advances in communication, and smaller family sizes allowing for accommodating home ownership (US General Office Accounting, 1999). The influence of such development practices has proven to weigh heavily on the relationship between the appropriate use of space, and transportation needs for urban sprawl occurring in post-war communities.

Smart growth planning principles and their influence on the development of transit corridors sought to create a liveable city. However, the discussion surrounding smart growth is not without its downfalls. Downs (2005) notes that the larger vision of smart growth, while future oriented and creative, is debated more than applied in reality. Smart growth policies are commonly discussed by planning departments yet rarely effective or adopted against established traditions, especially in rural and low-density applications. Smart growth has been made popular through the ideas of compact neighbourhoods, active transportation networks, and transit oriented development (TOD). This paper examines the relationship between smart growth and transportation, more specifically TOD and its implications on economic development.

Transit-Oriented-Development

Cities have become a creature of the automobile as driving an automobile is said to be a virtual necessity for most (Pollard, 2001; Wooley v. Maynard. 430 U.S 705. 715, 1977). The lack of alternative modes of transportation inclusive of public transit, walking, and cycling assumes driving as the main choice. Pollard (2001) argues that transportation policy needs to move past previous transport infrastructure policies that sought an unprecedented effort to construct vast highway systems in the United States and Canada. The push towards ensuring personalized automobiles had the necessary infrastructure hinders alternative options for transportation. Traffic congestion, a rise in the average trip length per household, and the lack of mobility for some has made TOD principles more attractive to new planning initiatives (Pollard, 2001). According to Handy (2005), four relationships were drawn out of smart growth and transportation land use development. First, the construction of new highways promotes urban sprawl and allows rural development to occur. Framed through the historical building of suburbs, the construction of highways advanced the increase of sprawl. Second, the construction of new highways directly results in a greater attitude towards personalized automobile travel. Supported by Kienitz (1999), the development of new roads fuel excessive population growth yet only provided short time relief. Third, the investment of light rail transit facilities was seen as a solution to increase density, a prime goal of smart growth (Cunningham and Cunningham, 2012). Light rail transit investment encourages a perception shift towards transit use however cannot solely promote TOD but acts as a pushing force of movement in regional areas. Finally, the implementation of new urbanism principles sought to provide greater opportunities to eliminate personalized automobile travel. New transportation alternatives also bring the development of an interconnected network of active transportation such as bike lanes, sidewalks, and trails.

Light rail transportation is a powerful development tool to deal with urban sprawl. This type of transportation infrastructure cannot promote smart growth or TOD on its own (Light Rail Now Writing Staff, 2002). TOD is commonly referred to as the 10-minute walking, or half-mile radius, area surrounding a transit station (Renne, 2009). TOD and smart growth integrate transportation networks, stations or hubs to clusters of housing and commercial activities allowing for strong connectivity. This connectivity boosts the relationship between ridership and provides a reliable transit market for communities (Geller, 2003). According to Handy (2005), this form of transit development is a powerful tool in shaping land use patterns in metropolitan regions.

Triple Bottom Line – Sustainability

The triple bottom line (TBL) refers to the sustainability framework where the social, economic, and environmental perspectives are taken into account and perceived throughout each phase of development to create greater (business) value (Slaper and Hall, 2011). These three perspectives, when combined, initiate sustainable development. Ultimately, sustainable development must incorporate the economic, social, and environmental perspective, throughout the planning and implementation process.

Due to numerous economic, social, and environmental impacts attributed to transportation, a logical starting point for reaching sustainable development is in transportation planning (Nichols et al., 2009). Identifying a suitable definition and quantifiable scale should be considered the starting point (Mihyeon Jeon and Amekudzi, 2005). As Banai (2005) argues, land development proposals should place an emphasis on long-term community conservation and urban growth in a sustainable way. Moreover a distinction should be made between the addition of short-term sustainable land development or comprehensive long-term development.

This research follows a similar assumption made by Williams, Jenks and Burton (2000) that measuring sustainability and urban form entails a variety of variables. Numerous forms of measurement such as density, compactness, concentration, dispersal, mix of uses, and housing types are various types of characteristics that shed light on urban sustainability and how a sustainable urban form is present (Williams et al., 2000).

Three classifications of indicators have been selected to ensure the full sustainable framework is observed: the economic framework is observed through measuring National Canadian Census economic indicators; the social framework is observed through measuring National Canadian Census social indicators; and the environmental framework is observed through measuring land cover type and satellite imaging to understand the degree of green space. This classification of variables follows Metrolinx's Baseline Monitoring Report (2013) and Di Febo et al., (2015) measurement of variables within the City of Toronto. The need to develop a framework for developing sustainability indicators for transportation planning is necessary as "what gets measured gets done" (Nichols et al., 2009, p. 1). A focus on sustainability and transportation is relatively new, providing no established set of indicators for assessing sustainability goals and transit systems (Nichols et al., 2009). Likewise, defining a sustainable transportation system is difficult given the various definitions of sustainability and the lack of acceptable framework (Jean, Amekudzi, and Guensler, 2013).

Sustainable City Development

In view of increasing global urbanization, a push towards allowing the urban environment to become more sustainable is required. Sustainability objectives are required for both the developed and developing world and may range from financial, technological, infrastructural, to urban planning strategies. By 2025 approximately 2 billion people, i.e., 25% of the global population will live in 600 world cities generating $64 trillion in gross domestic product (GDP) (McKinsey Global Institute, 2011c). This increase in populations and urbanization will pose both challenges and opportunities for sustainable city development.

Ensuring that sustainability is understood in respect to its demographic, consumption patterns, infrastructure, and resource depletion constraints are crucial (Pollalis et al., 2012). The alternative to sustainable development is economic, social, and environmental decay. To achieve sustainable development, citywide integrated urban sustainability must be implemented. Six general elements comprise sustainable urban infrastructure: energy; water; waste; transportation; landscape; and information, each element plays a critical role in the success and growth of a city economically, socially, and environmentally (Kammen and Sunter, 2016). Understanding sustainability at the city level is pivotal in the future success of cities. Moreover, ensuring that a city is developed without adverse health impacts to those living inside global cities is key (Karagianis, 2014).

A pressing issue surrounding urban sustainability is the attempt in forecasting supply and demand of existing and new real estate development. This supply and demand is driven by urbanization and met with constraints to the capacity to build new infrastructure. These constraints are grounded in issues related to government regulation and policy implementation, resource depletion, financial ability, and technological advances (McKinsey Global Institute, 2011b). Ensuring that the energy required to maintain and grow cities are practical and cost-effective, a cost-benefit analysis must be address by local government to measure existing forms of energy paired by new and emerging energy sources (McKinsey Global Institute, 2011a).

Types of infrastructure developed around transit nodes

Relationships between transportation, TOD, and high-density living have been studied extensively (Behan et al., 2008; Curtis, 2008; Downs, 2005; Lin and Gau, 2006; Smith, 1984; Steiner, 1994). Generally speaking there are three types of residential development types that may take place around a subway station:

1. Low-rise development: These structures are typically one to three storeys and possess less density per square foot as compared to alternatives forms. One case of low-rise development is the classification of a multifamily house (Urban Land Institute, 2015). Low-rise development may also be classified as both two story multifamily townhouses and single story apartment blocks (Urban Land Institute, 2014b). This type of development is typically discouraged in areas along major corridors or near highly transit accessible areas;

2. Medium-rise (midrise) development: These structures are typically four to 10 storeys. Medium-rise developments maintain a sustainable scale and relationship with its adjacent street and provide sufficient sunlight due to this scale. One case of midrise development is the classification of a multifamily apartment complex (Urban Land Institute, 2015). The rise of midrise surrounding transit hubs has successfully increase density, retail, and live/work spaces in downtown Vancouver (Urban Land Institute, 2014a). This rise in development type has been coined as an exemplary model of transit-oriented development. A typical application of midrise development would be along major corridors and avenues of a downtown city centre; and,

3. High-rise development: These structures are usually 11 storeys and higher. Commonly referred to as a tower block, these high-density structures depend on lifts to reach their destinations. While the exact number of storeys varies, both residential and commercial towers exceeding 15 stories have been classified as high-rise structures (Urban Land Institute, 2016). Condominium mixed-use buildings can exceed 30-40 storeys (Urban Land Institute, 2014c). The application of high-rise towers are most appropriate in nodes that are highly transit accessible, The access of transit allows for new residents to capitalize on the availability of transit and reduce personal automobile use.

High-density developments are typically encouraged through policy and government intervention surrounding major transit nodes (Smith, 1984). It is typically the medium and high-rise development projects producing higher density per square kilometer as oppose to low-rise development promoted in these areas. Hence, the emphasis is placed upon medium- and high-rise forms for intensive development once transit lines are proposed and developed. Both the private and public sector understand the joint partnership in developing high-rise (Cervero, 1994). My research has shown that in both the Metropolitan Vancouver region and City of Toronto, density rates significantly raised compared to respective larger areas. To ensure sustainability is brought to the micro-level, or individual case-by-case building level, standards and measures have maintained the process of reducing the amount of environmental impacts new construction faces. The Leadership in Energy and Environmental Design (LEED) program influences sustainable building design (Clevenger, 2008). Broadly speaking, demographics, changes to housing and neighbourhood characteristics are shaping transportation congestion, infrastructure development type, and resource-use compared to cities of the post war suburb (MacCleery, 2012; Stone and Mees, 2010).

Indicators identification and selection

Indicators have primarily been selected based on the availability of National Canadian Census data from 1981 and 2006. Canada’s three biggest metropolitan regions, Toronto, Montreal and Vancouver were studied. Following Di Febo et al., (2015), collected indicators are measured and analysed on their own without the influence of additional variables.

Economic Variables

Four variables collected from the National Canadian Census were used to measure the economic aspect of transportation planning and economic development: (1) average number of rooms per dwelling; (2) average value of a private dwelling; (3) average gross monthly rent; and (4) average household income.

Notable increases in economic variables on the basis of economic prosperity were noted. The gentrification issue raises both positive and negative externalities related to areas surrounding transit hubs experiencing higher dwelling prices (Norton, 2001). While a direct link is seen in those moving into the middle class and those currently within the middle class possessing a greater degree of economic freedom, it is the displacement of vulnerable residents that suffer both on an economic and social scale. These economic and social restrictions typically include a "derelict or low-quality housing area as a result of postindustrial trends" (Norton, 2001, p. 319). Common variables that adversely impact vulnerable residents are housing values that create a market to expensive for lower income individuals and increasing monthly rents forcing residents to move further away from transit options. Reductions in available transit alternatives are common outcomes associated with lower income individuals (Oreskovic et al., 2009).

Average value of private dwelling

The average value of a private dwelling or the commercial property value is intensified both by access and proximity to transit stations (Nelson, 1999). The relative increase in property value is significantly intensified surrounding transit stations. Hess and Almeida (2007) sought to quantify and calculate areas of greater property values in areas of close proximity to Buffalo's rapid transit system based on a station-by-station approach. An increase of approximately 2.5% of the median dwelling value was experienced in areas of an 800-meter buffer surrounding transit stations. Increased household prices are a direct result of the development of higher order rapid transit.

The selection of the average value of a private dwelling collected by the National Canadian Census was primed on the basis that areas in close proximity to transit hubs experience a larger impact in terms of increased housing values when compared to areas of further distance. This 'larger impact' is classified as a substantial increase in the net monetary value of a private dwelling.

Average number of rooms per dwelling

Residential property values are one characteristic influenced by the development of transit investment. A similar relationship between the availability or rooms and transit investment is noted. The number of rooms and bathrooms in newly build construction was a key indicator that noted an impact on residential property values near Seoul's Line 5 (Bae, Jun, and Park, 2003). The number of rooms was identified as a strong determinant for measuring the degree of influence the development of a transit system had on surrounding neighbourhood characteristics.

The development of transit largely influences the type of housing stock proposed and developed in adjacent areas. In typical TOD fashion, the development of high density residential or commercial is encouraged to significantly increase the population and employment in areas immediately surrounding transit hubs. Section 5, Types of infrastructure, further outlines the delineation between varying real estate types and the acceptability of high density building in areas immediately surrounding major transit hubs. Varying types of stock largely influence the dwelling cost, and the value attained for rent in the surrounding area. Hence, private dwellings containing fewer rooms, typical in condominium and high-rise development, are expected in areas surrounding transit hubs than the rest of the city.

Average gross monthly rent

Research on the proximity of rental locations and transit hubs prove a positive relationship. A strong connection is made linking residents living near transit hubs willing to pay a higher rate in terms of rent due to the 'efficient-location' affect. An increase in walking distance to transit hubs significantly reduces rental property priced between 5% and 10% (Rochman et al., 2015). Cervero (1996) identified a positive relation between the restriction of parking and automobile policies and those moving near transit hubs. Areas in close proximity to transit hubs demand a significantly higher rental cost when compared to those areas of distance. The willingness-to-pay for areas in close proximity to transit hubs are significantly increased as the value created towards consumers, lower commute times, appropriate access to transit hubs is increased (Valente, 2016).

Average household income

The impact of rising costs associated with living near a transit hub is greater for low and middle-income groups compared to higher income individuals (Boyce et al., 1974). Measuring change in household income is critical when understanding the change attributed to TOD. Within the field of transportation planning, the study of transit usage, density, and household income have previously been established (Frank and Pivo, 1994; Jones, 2015; Ram, 1988). Areas in close proximity to transit hubs generally house individuals with a greater average household income. It is ultimately the higher rental and dwelling values that signify a shift towards higher income earners moving into areas designated transit hubs and access to transit.

Social Variables

Two variables collected from the National Canadian Census were retrieved and used to measure the social aspects of transportation planning and economic development: population density and the average number of persons per household.

Population Density

According to Frank and Pivo (1994), areas with higher population densities when compared to alternative neighbourhood areas are usually accompanied with a greater demand for public transportation use. This use drives both public transit usage and density in areas accessible by transit. Likewise, Shah et al. (2013) support the notion that population density should be used in measuring transportation planning. Such an indicator is significant in its ability to reflect a higher potential demand for public transit. Positive relationships between increased density and a reduction in personalized automobile travel are common. An approximate 10% increase in density leads to an approximate 1% reduction in personalized automobile travel, thus transferring such trips to alternative forms of travel, typically public transportation (Schimek, 1996).

Such studies also corroborate with Steiner (1994) who asserts that willingness of individuals moving to high density areas are on three assumptions: (1) alternative modes of transportation are available to the consumer and is used beyond the personal automobile; (2) a variety of alternatives, inclusive but not limited to public transit and cycling is made available in the immediate vicinity; and (3) a change in travel patterns is made with higher density living conditions. Hence, areas that experience a greater increase in population density near transit hubs are aligned with principles of smart growth and TOD pertaining to sustainable real estate development and a reduction in personalized automobile usage.

Average number of persons per household

The average number of persons per household and the investment of transit normally create an inverse relationship. Regional areas with larger household sizes (usually measured as three or more individuals) are unlikely to use and adopt a transit-oriented method of travel (Shalaby, 1998a, 1998b). Household sizes of three or more individuals generally prefer to adopt the use of private vehicles as opposed to public transit from two perspectives. The initial is from an accommodation standpoint outlining that the use of personalized automobiles is easier to use for families, the second is from a monetary perspective. The cost of purchasing multiple yearly transit passes may be substantially less than to the cost of buying or leasing, insuring, and maintaining an automobile.

Adopting this theory, an inverse relationship is formed arguing that areas of smaller family sizes are likely to use transit systems hence reside beside transit systems. This information was collected and classified as the average number of persons per household.

Environmental Variables

Due to the absence of environmental data collected by national census surveys, a remote sensing analysis was performed and used to analyse the environmental aspect of transportation planning and economic development (as described below). A single variable, the removal of green space in areas immediately surrounding the specific and selected transit hubs, was therefore analysed.

The lack of environmental data and quantifiable results is a challenge when attempting to link transportation development to the provision or conservation of green urban spaces in cities. The National Household Survey, National Canadian Census, Statistics Canada, and Transportation Tomorrow Survey do not track measurable environmental statistics in relation to urban planning and economic development (Government of Canada, 2011; Statistics Canada, 2006; University of Toronto, 2013). This lack of quantifiable data makes it difficult to assess the environmental dimension of sustainability (Jeon et al., 2013; Nichols et al., 2009).

Green space

Due to the lack of quantitative datasets satellite imaging was selected as an appropriate measure. Satellite imaging was applied to measure the change in vegetation and green space levels within the indicated three study areas. Under this approach, an adjacent methodology was developed tracking and measuring the removal of green space (illustrated predominantly by vegetation) using remote sensing techniques. Attributed to urban development, patterns of development have emerged that restrict both the quantity and quality of green space (Jim, 2004). The limited provision of green space in cities pose both human health and biodiversity benefits (Fuller et al., 2007). The quantitative tracking of green space, when available, could be a key indicator in understanding whether the development of transit hubs has indeed adversely impacted the natural environment. Hence, in areas that have experienced a low percentage or removal of green space the argument put forward is that the development of transportation hubs has played some role in this removal.

Hypotheses

This research examines how variables within the 800-meter study area have been influenced to a greater degree of change compared to those outside of the 800-meter buffer (I recognize that the area outside this 800-meter is highly diverse and provides a general comparative approach). Two hypotheses are produced: a null hypothesis provides a significant change, and an alternative hypothesis provides no significant change. These hypotheses are expressed as:

H0: $\mu d = D$ or There is a difference between variables within the 800 meter study area or selected transit area compared to the metropolitan region constant between 1981 to 2006

H1: $\mu d \neq D$ or There is no difference between variables within the 800 meter study area or selected transit area compared to the metropolitan region constant between 1981 to 2006

Research designs that outline a null and alternative hypothesis must formally accept the null hypothesis or reject the null hypothesis. Hence, for each of the three study areas, the null hypothesis will be proven or disproven.

Assumptions

Three assumptions were made at the start of this study. Each assumption is critical to the acceptance of the methodology and results of this study:

1. In areas of close proximity to a transit hub, the changes experienced between the 1981 and 2006 census in social, economic and environmental, are attributed to the development of transit hubs;

2. The 1981 and 2006 census capture the percent change of each selected census variable without assuming data collection error; and,

3. Satellite imaging retrieved from the Landsat program captured the extent of urbanization and the removal of open space between 1981 and 2006 unless otherwise stated. As the Landsat 2 was launched in 1975 and Landsat 5 launching in 1984 the development of technology within that decade saw improvements in remote sensing instruments and ultimately satellite capture equipment (United States Geological Survey, 2016b, 2016d). When satellite imaging was deemed unacceptable due to a high rate of cloud cover or alternative variables that hinder the classification of land cover, an alternative analysis is carried out.

Research Design and Methodology

Three Canadian metropolitan regions are selected for this study: Metropolitan Vancouver, the larger region of the Greater Toronto Hamilton Area (GTHA), specifically the City of Toronto, and Metropolitan Montreal. These three regions are selected as they meet the criteria of possessing major transit hubs and transportation corridors, respectively the Montreal Metropolitan, Vancouver's SkyTrain, and the City of Toronto's Toronto Transit Commission (TTC). This research draws from three comprehensive transportation reports: Strategic Plan 2020 by the Société de transport de Montréal, the Transportation 2040 report by TransLink, and The Big Move 2030 regional transportation report by Metrolinx. Moreover, the availability of the Canadian Census for 1981 and 2006, along with Statistics Canada's geographic boundary files, allow for a comparison between these three areas. Details and findings for each city/region are presented in separate sections below.

This triple case study research into the regions of Vancouver, Montreal, and Toronto is followed as a specific hypothesis testing. The testing of variables may allow for the null hypothesis to hold true or for the alternative hypothesis to become valid (Yin, 1984). Moreover, a deductive research approach is adopted where a theory and hypothesis is tested from data analysis. Tests identify whether and to what degree a relationship exists between transit hubs and economic, social, and environmental indicators. The purpose of this approach is to allow further studies to be tested that allow for explanations and principles to be assessed in comparable regional cities. To primarily understand the degree of economic change in areas immediately surrounding a transit hub, an 800-meter network buffer was applied based on a census tract approach (Hess and Almeida, 2007; Hess and Sorensen, 2014).

Quantitative data was retrieved from the Canadian Census for the years of 1981 and 2006. The time period of 1981 to 2006 was studied to understand whether identified variables have changed over time. Both ending and beginning time periods have been strategically selected due to the validity of useable data. The 1981 time period was selected as it predates all selected transportation projects, while the 2006 time period postdates the full completion of all selected transportation projects. An assumption was made moving forward that the 1981 and 2006 census capture the percent change of selected variables.

Comparative research design

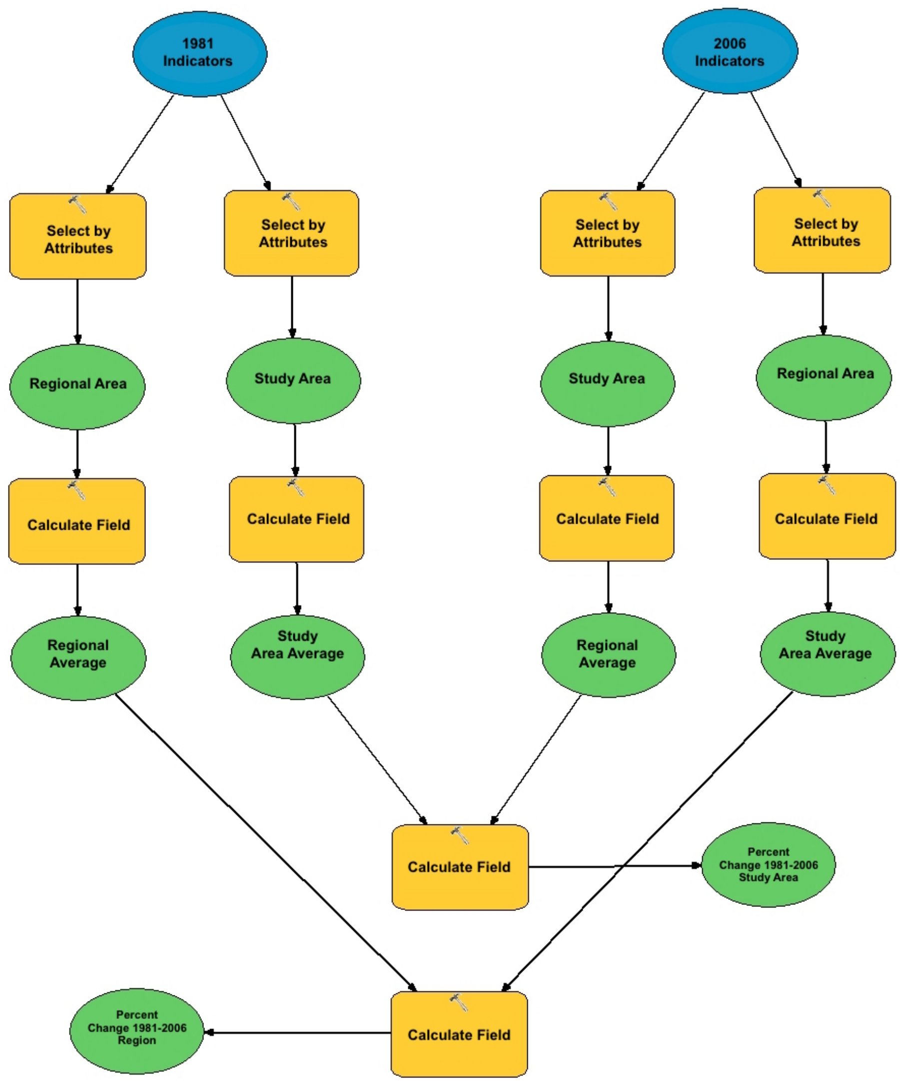
Initially, a single case study methodology was developed and selected analyzing the urban core of Vancouver and its associated transit lines. The initial assumption made that a strong correlation between economic, social, and environmental variables between the varying regions in Metropolitan Vancouver and its SkyTrain transit system would be similar if not identical to comparable regional cities in Canada. While Metropolitan Vancouver produced positive results, a multiple case study approach was ultimately adopted to produce multiple case studies. Thus, two additional major economic regions were chosen, the City of Toronto, and Metropolitan Montreal.

On the basis of research design and methodology, choosing a multiple case study comparative design allows for similarities and differences to be highlighted. These similarities and differences were used to generate and assess existing theories. Bryman, Bell and Teevan (2012) argue that this outcome allows for strength in identifying patterns when developing a quantitative case study comparative design. Selecting multiple case studies strengthen the results of hypotheses as identified patterns are replicated and increase the robustness of findings. Moreover, the lack of identifying similar patterns increases the doubt of an argument (Vohra, 2014).

Canadian census data analysis

Two methodology frameworks were developed for this research**.** Figure 1 outlines the initial methodology. This methodology applies basic statistical measures to quantify and calculate indicators (De Veaux, Velleman and Bock, 2009).

Figure 1: 1981 to 2006 Canadian Census Comparative Analysis (Methodology Model)



Source: Michael D. Di Febo

Two main equations were used to develop the methodology model outlined in Figure 1. The rate of change and average equations are outlined in Equation 1 and 2.

Rate of Change

The rate of change is a ratio between the present and past-related quantities (Slavin, 1989). This rate of change outlines the degree to which economic, social or environmental variables have changed between the 2006 and 1981 time period. The equation is as follows:

$$Rate\ of\ Change = \left(\frac{Present_V - Past_V}{Present_V}\right) x\ 100 \qquad (1)$$

where $Present_V$ and $Past_V$ is the retrieved value as per the 2006 National Canadian Census and is the retrieved value as per the 1981 National Canadian Census.

Average

The average or mean is the sum of all numbers in a dedicated list, divided by the total number of items within that list (Slavin, 1989). This equation is applied to individual indicators to calculate the average rate of change as follows:

$$Average = \frac{\Sigma^X}{N} \qquad (2)$$

where X is the average of all numbers, and N is the total number of items within the list.

Remote sensing analysis

A remote sensing analysis was used to track changes in environmental variables as per the three higher order rapid transit lines in Metropolitan Vancouver, the City of Toronto, and Metropolitan Montreal. The associated satellite imaging adopted is the Landsat Satellite Series that were commissioned by the Government of United States and NASA (United States Geological Survey, 2016e). The Landsat program has seen the deployment of 8 satellites up to date.

This research uses imaging sets from various satellites within the Landsat program. Landsat 2 launched on January 22 1975 and was decommissioned on July 27 1983 (United States Geological Survey, 2016b). The Landsat 2 program has an 80m resolution in the multispectral band and detects all seven multispectral bands. The Landsat 3 probe was launched on March 5, 1978 and decommissioned on September 3, 1983 (United States Geological Survey, 2016c). Landsat 3 records eight bands in the 40m resolutions from two 80m-resolution cameras. Landsat 5 launched on March 1, 1984 and was decommissioned in June 5 2013 collecting seven spectral bands from the 30m to 120m ranges; this study applies bands one to seven (United States Geological Survey, 2016d).

The satellite imaging dates and data sets collected for this research are as follows:

- Metropolitan Vancouver: Landsat 3 (August 29, 1980 and August 6, 1981) and Landsat 5 (October 11, 2006).
- City of Toronto: Landsat 2 (August 1, 1981) and Landsat 5 (October 9, 2006).
- Metropolitan Montreal: Landsat 3 (September 16, 1980); Landsat 2 (July 11, 1981) and Landsat 5 (August 27, 2007 and September 5, 2007).

When satellite imaging was not available for 1981 and 2006, one year before of after this period was deemed acceptable. Moreover, where satellite paths and rows did not align with entire metropolitan areas, multiple satellite images were joined to create a cohesive picture.

Due to the aging satellite systems used in this study, in addition to the now decommissioned satellite technology, the noted remote sensing 1981 to 2006 rate of change analysis was not conducted for Metropolitan Vancouver and Montreal. In its place a secondary environmental analysis was performed for 2006. This secondary methodology uses satellite imaging from 2006 to identify the quantity of urban (open but not necessarily green), green spaces, and hydrology in square kilometers. Following this, the percentages of each are compared between the study area, which happens to fall within the urban core, and the entire region. This rough calculation sought to understand whether the percentages of environmental provisions are similar or drastically different in the urban core study area and regional area. The identical methodology for developing land use cover was used, however oppose to tracking the amount of green space removal between 1981 and 2006, a comparison for 2006 was performed outlining the percentage of vegetation within the study area to the entire metropolitan area.

Composite Band

The composite band data management tool in ArcGIS is used to create a single editable raster file from multiple satellite images, or satellite bands (Chang, 2010; ESRI, 2016b) This interface allows for multiple raster's to become classified in an ordered fashion. This research adopted the composite band tool for data management purposes (ESRI, 2016a). Bands one through seven were compressed into a single editable allowing for further analysis.

Iso Cluster Unsupervised Classification

The main tool used to develop the remote sensing model was the Iso Cluster Unsupervised Classification. This tool classifies all seven Landsat bands into an editable file using an interactive optimization clustering procedure (Chang, 2010; ESRI, 2011). The algorithm classifies cells into a user specified output, in this programs case seven, distinct uni-modal group within the total space of the multiband raster (Ball and Hall, 1965). Greater controls over classification parameters are used when using an iso cluster unsupervised classification. The Iso Cluster Unsupervised Classification identifies patterns of urbanization, vegetation, and hydrology and produces a unique value indicative of varying levels of urbanization, vegetation, and hydrology ultimately proving a classification. The classification or clustering is outlined in equation 3 as follows:

$$Z = \frac{(X - oldmin) x \, (newmax - newmin)}{(oldmax - oldmin)} + new\ min \qquad (3)$$

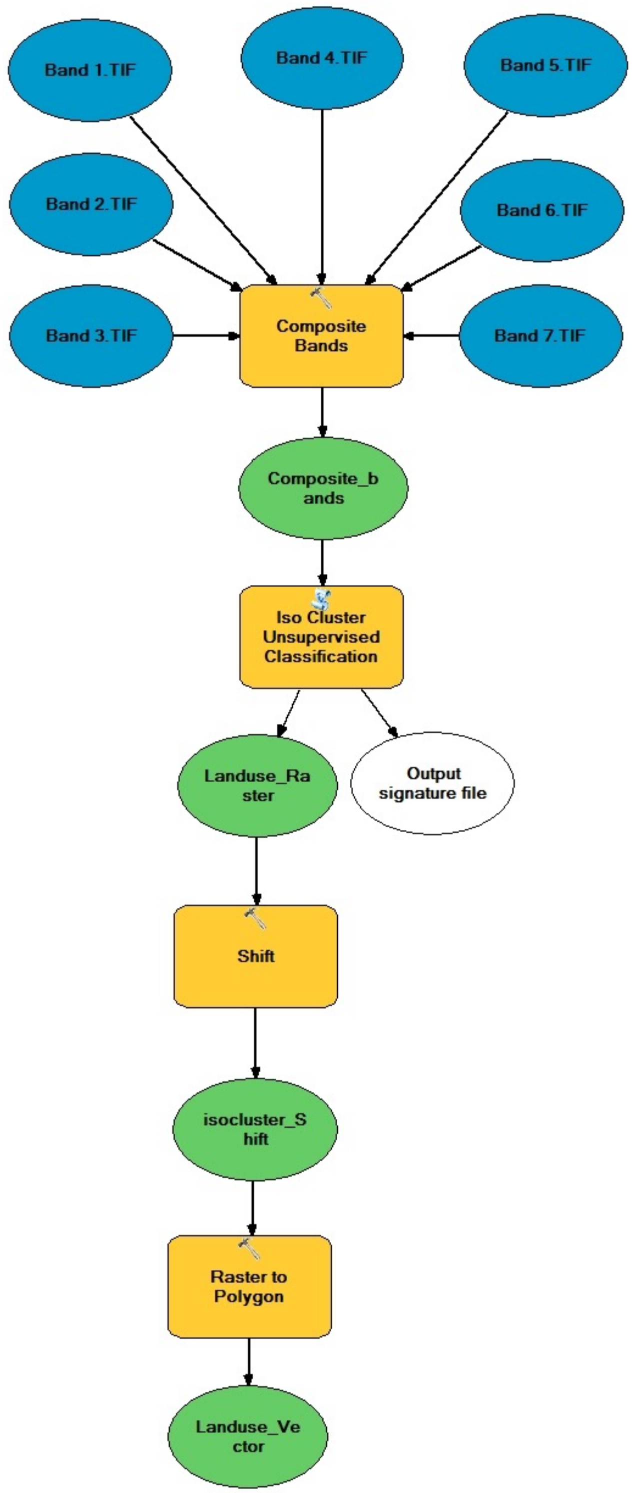
where *Z* is the output raster with new data ranges, *X* is the input raster, *oldmin* is the minimum value of the input raster, *oldmax* is the maximum value of the input raster, *newmin* is the desired *minium* value for the output raster, and *newmax* is the desired maximum value for the output raster" (ESRI, 2016c, p. 1).

Methodology for classification

The removal of green space within the urban core was the best measure available to track the effects of transit development on the immediate study area. Green space has been classified into six categories: light vegetation; medium vegetation; high vegetation; low water / hydrology; and deep water / hydrology. The remaining category "urban" outlines largely impervious surfaces that adversely impact the quality of natural environments (Barnes, Morgan III and Roberge, 2000). In this research, the initial five categories are classified as environmental variable and used to outline adverse impacts within the study area and metropolitan region.

In cases that satellite imaging was deficient, the secondary remote sensing analysis is performed. This analysis seeks to compare the percentage of urban, and green space within the selected study area to the larger regional study area. The following discussion outlines whether results produced show a similar or drastic change in the amount of urban and green space between the two.

Figure 2: Remote Sensing (Methodology Model)



Source: Michael D. Di Febo

Metropolitan Vancouver

This section presents the census analysis in the region of Metropolitan Vancouver and the selected SkyTrain area. Variables were measured and identified to measure what degree changes have been made between the 1981 and 2006 time period. Due to inconsistencies in satellite imaging between the 1981 and 2006 time period the primary comparative remote sensing analysis was not possible. Instead, a secondary analysis representing the percentage of green space in the study area and larger Metropolitan Vancouver is presented. This identifies whether the urban core of Metropolitan Vancouver possess similar characteristics pertaining to the percentage of green space, urban core, and hydrology to that of the larger region.

The study area within Metropolitan Vancouver produced conventional transit-oriented development, and smart growth results. While some inconsistencies are present that may be attributed to policy change or internal issues related to the region of the Metropolitan Vancouver government, the null hypothesis is highly accepted and considered valid.

Context

Metropolitan Vancouver is both a regional district and metropolitan area in the Greater Vancouver area. Situated along the west mainland of British Columbia, Metropolitan Vancouver is the most populated coastal seaport in British Columbia. TransLink, the regional transit authority, provides transportation alternatives and operates within the larger Vancouver region. As TransLink is present throughout the entire regional district, analyzing the larger Metropolitan Vancouver is necessary oppose to a single city, such as the City of Vancouver, or the City of Burnaby which both possess portions of the SkyTrain's transportation system. Moreover, with the construction of the SkyTrain available throughout the region, the entire area of Metropolitan Vancouver was selected for this study due to the availability of data, construction time periods, and most importantly the type of infrastructure present throughout TranskLink's system.

In the years prior to 1986, the Region of Vancouver experienced rapid expansion and development attributed to the 1986 World Exposition on Transportation and Communication (Ross and Staw, 1986). The World Expo was used as an inner city redevelopment tool providing impacts to housing and urban planning throughout the region (Old, 1988). The approximate $800 million investment for the Expo provided areas with rapid infrastructure expansion and improvement, ultimately shifting travel patterns through newly developed transit lines.

Metropolitan Vancouver is analysed assuming an area consisting of Electoral District A, Lions Bay, Bowen Island, West Vancouver, North Vancouver (District), North Vancouver (City), Anmore, Belcarra, UEL, Vancouver, Burnaby, Westminster, Richmond, Delta, Port Moody, Coquirtam, Port Coquirtam, Pitt Meadows, Maple Ridge, Delta, Surrey, Langely City and Langely Township. As per the governing administrative boundaries outlined by the Government of Canada, the 23 areas are identical in both the 1981 and 2006 census years (Government of Canada, 1981, 2006).

Metropolitan Vancouver Transit Agency

Transport 2040 report outlines both the regional and local goals of TransLink, the regional authority governing transportation in the greater Vancouver region (TransLink 2008). TransLink (2008) outlines four broad strategies linking future transit planning to the overall economic development of the region:

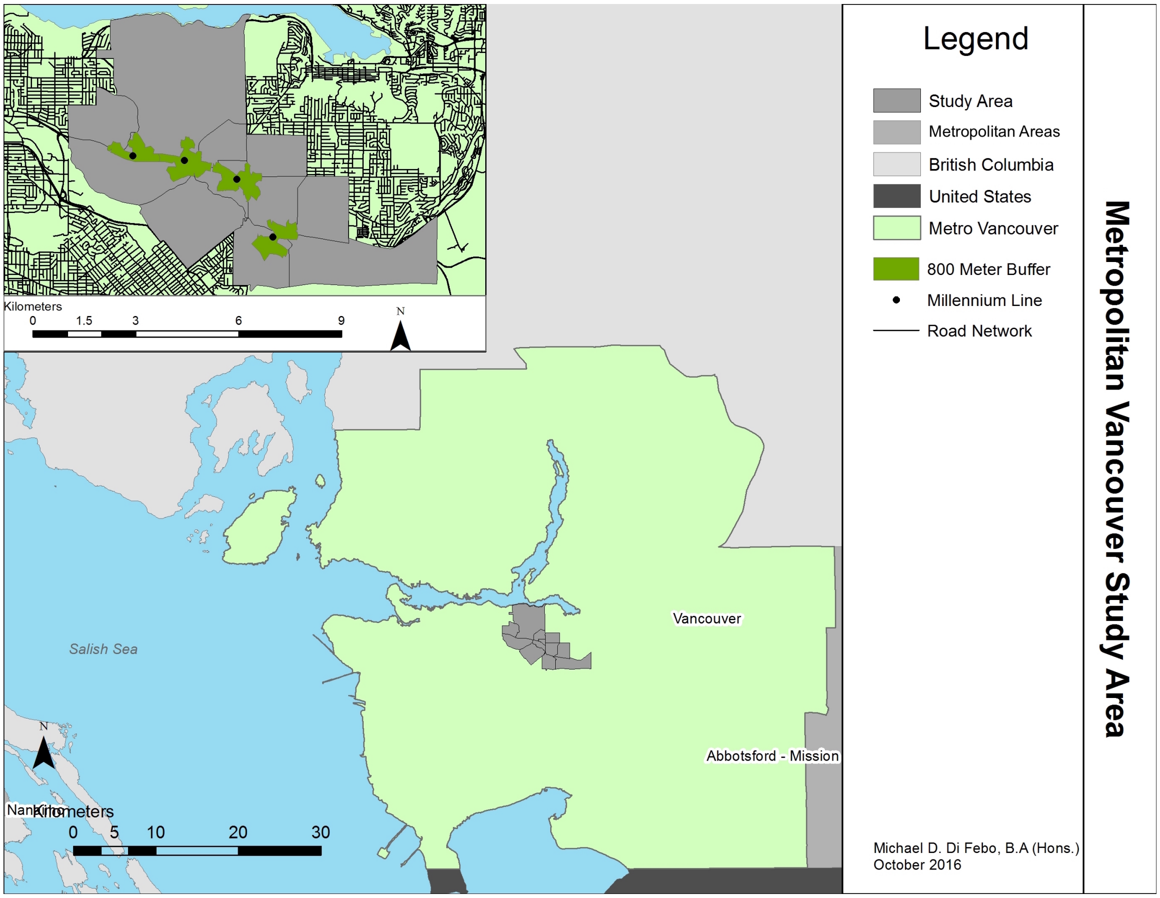
(1) Early investments that encourage development of communities;
(2) Optimization of the region's transportation assets;
(3) Building and operating a safe, secure, and accessible transportation system; and
(4) Diversification of revenue sources and the pursuit of new and innovating ways to fund transportation.

These four strategies possess a strong correlation towards the potential for economic development in the region and future transportation projects.

The entire SkyTrain system length is approximately 80 km long and adopts a complete electrification of its system at an average speed of 45 km/h (TransLink, 2016). Depending on station and location, headway throughout the SkyTrain system ranges from three to 30 minutes. A standard track gauge of 1,435 mm is used throughout the system that allows for 2, 4, or 6 train set cars.

This study measures four SkyTrain stations along the Millennium Line at an approximate length of 6 kms out of 23.5 kms for the line. The four stations measured are: Lake City Way, Production Way-University, Lougheed Town Centre, and Braid. Figure 3 outlines the Metropolitan Vancouver study area both at the city and SkyTrain scale.

Figure 3: Metropolitan Vancouver Study Area



Source: Michael D. Di Febo

Indicators

Multiple census indicators were selected between 1981 and 2006. When observing social indicators, data related to population, population density, and average number of persons per household were retrieved. When observing economic indicators, the average number of rooms per private dwelling, the average value of a private dwelling and average monthly gross rent were retrieved. Finally, green space is analysed within the specified study area and larger region as a whole. This analysis adopted Landsat satellite imaging that mapped the removal of green space based on 800-meter buffers surrounding mentioned transit nodes.

Social and Economic Analysis

Table 1 presents raw census data for 1981, 2006, and the rate of change. Cells highlighted in bold depict entries that are greater between the study area and regional values. Data show that population density, the average value of private dwellings, the average monthly gross rent, and the average household income of the selected SkyTrain areas have grown more rapidly between 1981 and 2006 than in its metropolitan counterpart. Conversely, the overall population, number of persons per household, and the average number of rooms per private dwelling of the selected SkyTrain areas have grown more rapidly than in Metropolitan Vancouver for the same period.

Table 1: Social and Economic Indicators Metropolitan Vancouver and Selected SkyTrain Areas, 1981 and 2006

Census Periods		1981		2006		Rate of Change (%)	
Variables		Areas					
		Metro Vancouver	Selected SkyTrain Area	Metro Vancouver	Selected SkyTrain Area	Metro Vancouver	Selected SkyTrain Area
Social Indicators	Population	1,268,183	41,967	2,116,576	63,445	**67%**	51%
	Population Density	443	1050	502	1,442	14%	**37%**
	Average # persons per household	2.69	2.67	2.685	2.546	**0%**	-5%
Economic Indicators	Average # of rooms per private dwelling	5.806	5.834	6.422	6.073	**11%**	3%
	Average value of private dwelling	$166,214	$150,788	$256,228	$415,715	54%	**176%**
	Average gross rent (monthly)	$433	$422	$667	$827	51%	**96%**
	Average household income (Annual)	$38,808	$28,537	$63,611	$79,878	121%	**180%**

Environmental Analysis

Table 2 provides insight into the amount of green space during the 1981 and 2006 time periods for both Metropolitan Vancouver and the selected SkyTrain areas. The value represents the amount of square kilometers of green space as defined in the Section 1 – Introduction: Methodology.

As outlined, inconsistencies in data pertaining to *the significant addition of green space* have been noted between 1981 and 2006. This has not been the case with the urbanization process occurring within the 25 year time period of the region, more so the urban core of the study area. Such inconsistencies are attributed to unsatisfactory satellite imaging and cloud cover collected from the Landsat 3 probe.

Due to inconsistencies in the collected data, a secondary analysis for the later time period of 2006 has been performed which outlines the percentage of total green space throughout the study area and city. Three classes have been outlined (1) hydrology, (2) urban, and (3) vegetation. The methods outlined in Section 1 Introduction: Methodology pertaining to the generation of measurable files continue to apply to this analysis as the creation and classification performed is identical to later sections.

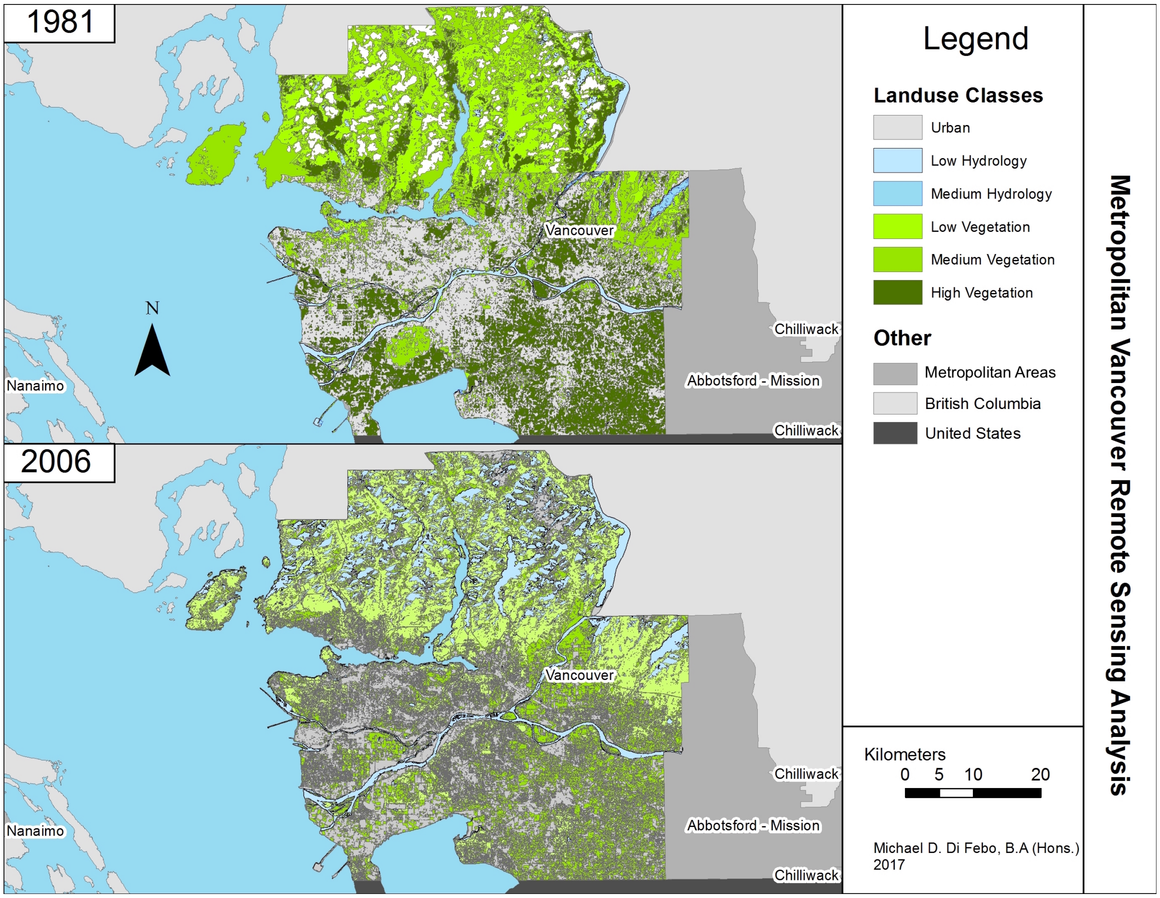
Table 2: Green Space in Metropolitan Vancouver and Selected SkyTrain Areas in 1980 and 2006

Census Periods		**1981**		**2006**		**Rate of Change (%)**	
Environmental Variables		**Areas**					
		Metro Vancouver	**Selected SkyTrain Area**	**Metro Vancouver**	**Selected SkyTrain Area**	**Metro Vancouver**	**Selected SkyTrain Area**
Primary Analysis	Open spaces (in km^2)*	2,171 km^2	14.5 km^2	2,378 km^2	28 km^2	10%	47%
Secondary Analysis	Hydrology coverage (%)	--	--	12.9%	4.5%	--	--
	Vegetation coverage (%)	--	--	65.4%	59.5%	--	--
	Urban coverage (%)	--	--	21.8%	35.9%	--	--
	Total coverage (in km^2)*	--	--	3,039 km^2	43 km^2	--	--

Note: The primary analysis uses km^2 as a unit of measurement and has been rounded to the nearest 0.5 km^2 while the secondary analysis uses a percent change.

Figure 4 outlines the imaging used in the secondary analysis to measure hydrological, vegetation and urban coverage in 2006. The scale of this imaging makes it difficult to read the specific loss of green space even though it is likely that urbanization has reduced green spaces.

Figure 4: Metropolitan Vancouver - Remote Sensing Study Area



Source: Michael D. Di Febo

Discussion

A distinct difference is drawn between the terminology of ‘increase’ and ‘decrease’, oppose to ‘positive’ and ‘negative’ when pertaining to the influence a change in economic, social and environmental variables have on immediate surrounding neighbourhoods. This research predominately focuses on the percentage change increase and decrease in variables oppose to establishing a stance on the issue of positive and negative community effects. A brief outline and description of such positive and negative impacts are however mentioned throughout this research.

Increases in social and economic variables have been researched arguing adverse impacts on the immediate surrounding community (Kahn, 2007; Lehrer and Wieditz, 2009; Lin, 2002; Rose, 1995). Gentrification is the process of changing a district so that it adheres to the middle-class pushing lower income individuals out, thus changing an neighbourhood to meet the influx of affluent residents (Lin, 2002; Dawkins et al., 2016). The link between gentrification and urban development has indeed proved adverse results such as displacement of existing residents by wealthier residents. Kahn (2007) concludes that new transit-oriented communities with built-up rail systems between 1970 and 2000 were gentrified to a greater extent. Those residing between ‘park and ride’ stations experienced more social homogeneity in the effects of rail transit compared to those receiving access to new ‘walk and ride’ stations. The appeal of living beside a pedestrian friendly area oppose to a large scale commuter lot was the result of gentrification in 14 major United States cities (Kahn, 2007).

However, such increases in variables may also induce positive impacts on the immediate surrounding community and result in the creation of wealth (Boyce et al., 1974; Cervero, 1994). The creation of wealth through increasing transit access, higher wages, increasing densities, rising rental values, and development of a new community may result in positive results for some.

The social and economic analysis results of Metropolitan Vancouver outline a typical smart growth and transit-oriented development scenario. The construction of transit appears favourable to economic development. A relationship between economic variables being housing characteristics, income, and rental values all increase in areas immediately surrounding transit hubs oppose to areas throughout the larger region. Advancements in economic development are typically linked with an increase in density, a main argument behind transit-oriented development (Canadian Urban Transit Association, 2004). An initial step of asserting that TOD has been implemented within an area is the increase of density, particular in the way of high-rise development. High-rise development typically refers to the development of residential or commercial structure upwards of eleven storeys. The promotion of ‘smart principles’ around financial, regulatory, infrastructure, and policy practices that aim to coordinate transportation and land use planning are exemplified through the increases in density and limit sprawling infrastructure (Geller, 2003; Miller and Hoel, 2002; Nurul Habib, Day, and Miller, 2009). The ideas that throughout the increase in social and economic variables, positive relationships are drawn that maintain urban sprawl.

As mentioned previously, Metropolitan Vancouver experiences typical TOD and smart growth change in terms of the change to socioeconomic variables. Patterns experienced within the region largely follow a typical scenario of growth spreading over the 25 year time period selected for this study. Long-range planning goals are in accordance with urban development patterns produced in this research. Such outcomes corroborate with the Neptis Foundation report stating that approximately 80% of the City of Vancouver growth was attributed to downtown intensification (Ashley et al., 2010). Moreover, the study area outlined in my research aligns with the findings of Walks (2008), who argues a level of gentrification within downtown Vancouver. Walks (2008) measurement of gentrification is through a significant change in rent levels and dwelling values. Such variables align with those selected in my research. On this basis, an argument is drawn that the larger processes of urban growth in downtown growth have been studied in similar research designs and convey a significant change in variables between 1981 and 2006.

Social and economic indicators such as population density, the average value of a dwelling, average gross monthly rent, and average household income increased to a higher degree in the selected SkyTrain areas than its metropolitan counterpart. The average number of persons per household is a significant indicator as relatively large household sizes show that people are unlikely to take advantage of public transportation as the appeal of personalized automobile usage is more attractive (Shalaby, 1998a, 1998b).

As outlined in Table 2 the study area falls within the urban core and has a low percentage of hydrology and vegetation features when compared to the rest of the city. This is common with many of the urban metropolitans and typical in the range of land uses available. Urban cores tend to contain a lower percentage of green space, as transportation systems, commercial and residential real estate, and asphalt tend to be predominant features. Generally speaking, a lack of green space challenges the sustainability of the urban environment as it relates to urban wildlife populations, urban living, and human health (James et al., 2009). Ensuring the protection of green space largely benefits both human health and the overall ecology in cities. While there is a greater percentage of green space in the larger region, the degree to which there is a higher percentage space is not as significant as comparable cities. At approximately 64%, environmental consideration makes up a notable portion of the study area in Vancouver. Such proportions have been noted to create tangible benefits for those living in the area (Hobden, Laughton, and Morgan, 2004). Ensuring the provision of green open space in the urban core of the downtown is evident throughout multiple planning policies and documentation (Metropolitan Vancouver, 2011, 2016). As Bylaw No.1136 Goal 3 states, to "Protect the environment and respond to climate change impacts" will be accomplished through four strategic strategies:

- S3.1 to protect conservation and open green space/recreation lands;
- S3.2 to protect and enhance existing natural features and their connectivity;
- S3.3 encourage land use and transportation infrastructure options that reduce energy consumption, greenhouse gas emissions, and improve air quality; and,
- S3.4 to encourage land use and transportation infrastructure that improves the ability to withstand climate change impacts and natural hazard risks.

These strategies emphasize the need to protect existing green space, protect sensitive environmental lands, and manage the degree of urbanization occurring within the existing built up area of Metropolitan Vancouver (Metropolitan Vancouver, 2011).

In the case of Metropolitan Vancouver and the selected SkyTrain areas, the null hypothesis is accepted arguing that there is a difference between variables within the 800-meter study area when compared to the city constant between 1981 and 2006. These differences confirmed that development of the Millennium Line has created demographic and economic growth around the selected stations.

City of Toronto

This section presents the census analysis in the City of Toronto and the selected Toronto Transit Commission area. Variables were identified to measure what degree changes have been made between the 1981 and 2006 time period. The above noted Canadian census and primary remote sensing methodology was followed throughout the City of Toronto case study.

The study area within the City produced somewhat conventional transit-oriented development and smart growth results. Some indicators followed a standard definition of theories while others defected from the norm. Provided the noted outcomes, there is an apparent relationship between the development of transit and influence on selected variables. The null hypothesis has been accepted in the case of the City of Toronto.

Context

The Greater Toronto Hamilton Area (GTHA), and specifically the City of Toronto is the most populous region in Ontario. The GTHA is home to approximately 8 million residents, the region is the most populated in Canada proving the necessity to move people adequately and efficiently (Government of Canada, 2011; Metrolinx, 2008). This research focuses on the City of Toronto as nearly 20% of the entire province's population resides within the City. On this basis, the City of Toronto, rather than the GTHA, has been selected to study within the context of the Big Move 2030 Regional Transportation expansion plan.

National Canadian Census information for the 1981 and 2006 years have been retrieved and studied throughout the duration of this research. As mentioned previously, unlike the entire metropolitan regions of Montreal and Vancouver, the municipality of the City of Toronto is selected for study.

The Big Move 2030 (Metrolinx)

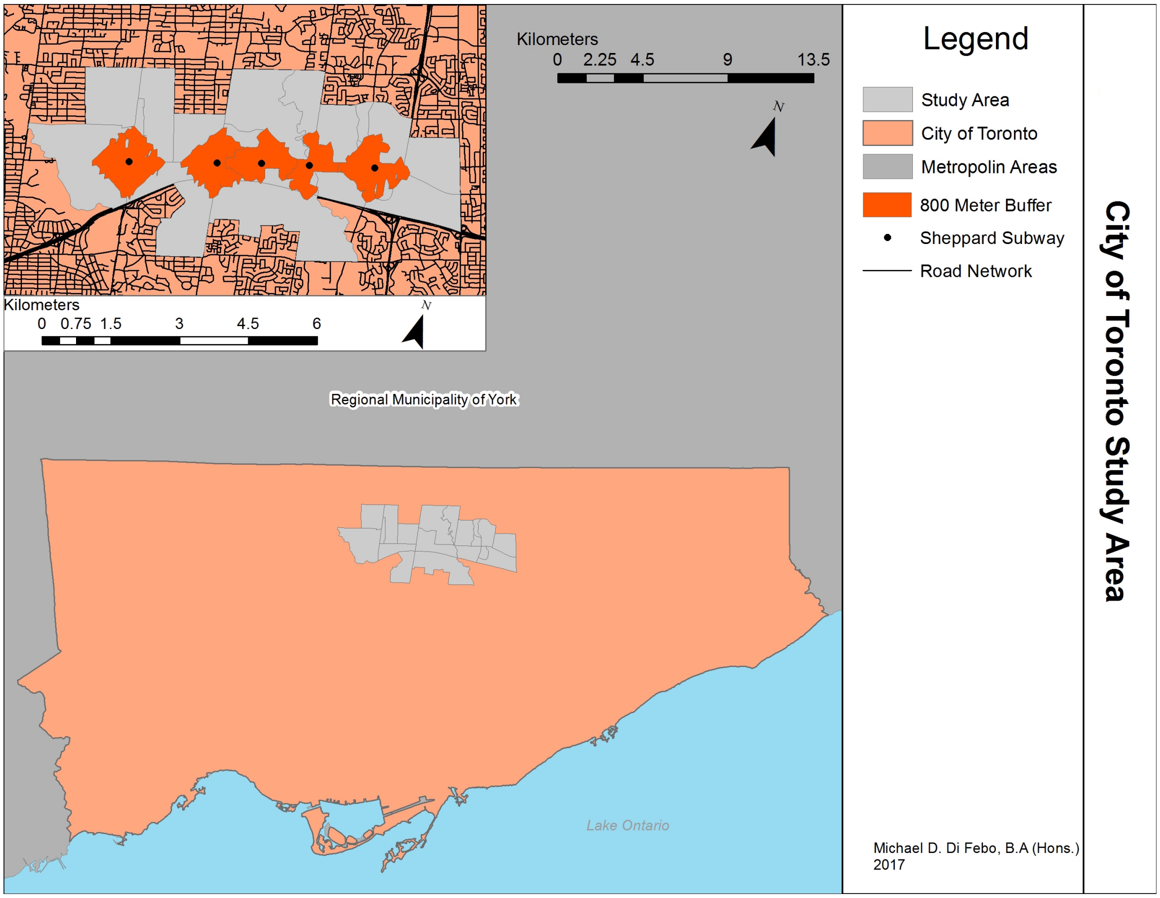
Metrolinx, an agency of the Government of Ontario, released The Big Move 2030 regional transportation expansion plan in 2008, outlining future transportation infrastructure decisions throughout 2030 for the entire Province of Ontario. The report outlines transit and transportation infrastructure improvements into short and long-term phases. While the Big Move sought to outline a regional transportation plan for the entire Province of Ontario, the majority of infrastructure funding and project are located in the GTHA, specifically in Toronto (Metrolinx, 2008). Similar to the Strategic Plan 2020, Metrolinx (2008) outlines goals, objectives, strategies, and forward thinking policies to ensure the continued investment of transit and infrastructure in the GTHA. Three goals drove the formulation of this plan:

(1) Looking forward and future oriented thinking;
(2) An appropriate investment strategy; and
(3) Ensuring a suitable implementation (Metrolinx, 2008).

These three approaches outlined in detail how the GTHA region as a whole is expected to grow through transit investment ultimately serving new settlement areas, improving existing ones, and establishing a strong case for economic development in the region.

As of 2017, the TTC subway system has a route length of approximately 66 kms (Toronto Transit Commission, 2016). The Sheppard Line 4 has an approximate route length of 5 kms adopting a 1,495 mm track gauge particular to the city and the TTC. This study measures five TTC stations along the Line 4 subway that fall within the 1981 and 2006 timeframe. The five stations measured throughout this research are: Sheppard–Yonge, Bayview, Bessarion, Leslie, and Don Mills. Figure 5 outlines the City of Toronto study area both at the city and TTC scale.

Figure 5: City of Toronto - Study Area



Source: Michael D. Di Febo

Social and Economic Analysis

Table 3 presents raw census data for 1981 and 2006 and the rate of change. Cells highlighted in bold depict entries that are greater between the study area and regional values. Data have been classified into two categories: social and economic variables. Where required**,** average of variables were calculated. Cells highlighted in bold show entries that are greater between the selected TTC areas and city values. Variables which experience a large increase within selected TTC areas oppose to the city are population density, the total number of unemployed individuals, the average number of rooms per private household, and the average gross monthly rent. Conversely, variables that experienced greater increases within the city opposed to selected TTC areas are the average number of persons per household, the average value of a private dwelling, and the average household income.

Table 3: Social and Economic Indicators for the City of Toronto and Selected TTC Areas, 1981 and 2006

Census Periods		1981		2006		Rate of Change (%)	
Variables		Areas					
		City of Toronto	Selected TTC Area	City of Toronto	Selected TTC Area	City of Toronto	Selected TTC Area
Social Indicators	Population	2137395	87822	2495081	114555	17%	**30%**
	Population Density	3376.6	3136.5	3942	4582	17%	**46%**
	Average # persons per household	2.757	2.823	2.7	2.653	**-2%**	-6%
Economic Indicators	Average # of rooms per private dwelling	6.075	5.566	5.716	5.822	-6%	**5%**
	Average value of private dwelling	118139	134747	408440	443592	**246%**	229%
	Average gross rent (monthly)	366	429	952	1168	160%	**172%**
	Average household income (Annual)	28019	33943	85388	92804	**205%**	173%

Environmental Analysis

Table 4 provides insight into the amount of green space during the 1981 and 2006 time periods for both the City of Toronto and the selected TTC areas. Table 4 outlines the associated measured green space in areas surrounding selected TTC areas in the City of Toronto as a percentage. The noted methodology was adopted for the City of Toronto as the retrieved satellite imaging was consistent in nature and contained zero or minimal cloud coverage that would hinder the adoption of the specified primary methodology.

Table 4 outlines a reduction in green space from 2.6 kms^2 to 0.5 km^2 within the study area representing a decrease of 81%, and 76.5 kms^2 to 39.0 kms^2 within the City representing a decrease of 49%. This decrease in green space in an area that experienced extensive infrastructure investment is typical and thus proves measurable for the City of Toronto. Similarly, a significant degree in the amount of green space reduction is experienced in both selected TTC areas and the City of Toronto.

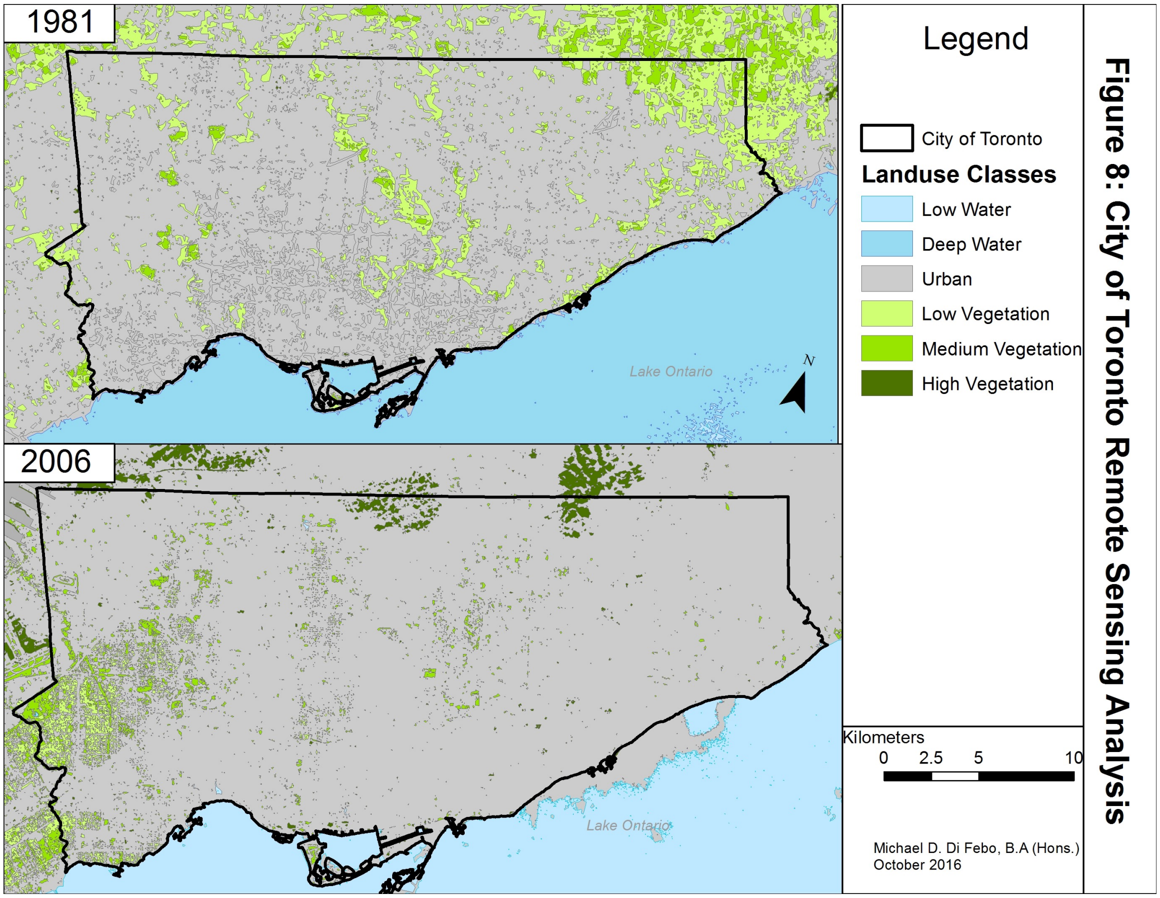
Table 4: Green Space in the City of Toronto and Selected TTC Areas in 1980 and 2006

Census Periods		1981		2006		Rate of Change (%)	
Environmental Variables		Areas					
		City of Toronto	Selected TTC Area	City of Toronto	Selected TTC Area	City of Toronto	Selected TTC Area
PRIMARY ANALYSIS	Green space (km^2)*	76.5 km^2	2.6 km^2	39.0 km^2	0.5 km^2	-49%	**-81%**

Note: The primary analysis uses km^2 as a unit of measurement and has been rounded to the nearest 0.5 km^2.

Figure 6 outlines the imaging used in the primary analysis to measure hydrological, vegetation and urban coverage in 1981 and 2006. There seems to be a particular problem with the images as Toronto appears to have lost a significant amount of green space in 2006 compared to 1981 – which is not necessarily the case based on my experience.

Figure 6: City of Toronto - Remote Sensing Study Area



Source: Michael D. Di Febo

Discussion

The City of Toronto proves somewhat conventional TOD and smart growth theory assumptions for the numerous economic and social indicators selected. Net increases and decreases in such variables align with traditional TOD and smart growth theories. In terms of population density, the areas surrounding Line 4 experienced a significant increase of 46% growth in population density, compared to 17% for the rest of the city. This increase is directly attributed to transit-oriented development and smart growth principles. Handy (2005) argues that as higher land values are typically associated with higher densities during real estate development, there is a proposition that the development of rail systems directly results in increased densities around stations. TOD principles argue that due to the availability of transit, the development of increased density through condominium construction is promoted, and ultimately change travel patterns in the immediate surrounding area (Curtis, 2008; Lin and Gau, 2006). The net increase in density in selected TTC areas is exemplified in official City policy and planning justifications that emphasize how transit development and population should be linked within the city:

- Chapter 5 S5.1.1 the City of Toronto Official Plan coherently outlines height and density incentives within specific pockets of the city (City of Toronto, 2015); and,
- As per the Secondary Area Plan 9: Sheppard East Subway Corridor (City of Toronto, 2006);
    - 9.2 (g): Higher mixed used density will be compatible in height and scale in areas surrounding the transit corridor; and,
    - 9.4.2.2 (b): assemblies set out to achieve maximum density will be encouraged with the Sheppard Corridor.

The number of large family sizes dropped within the study area compared to the rest of the city as a result of the type of development being made available in the area. Families of large sizes tend to avoid condominium type living conditions. The number of large size families using transit significantly drops due to the lack of availability (Shalaby, 1998a, 1998b). Moreover, the indicator of the average gross monthly rent rose 172% within the selected TTC areas compared to 160% throughout the entire city. This increase in rent in areas adjacent to transit lines compared to neighboring communities is common in TOD and city planning (Benjamin and Sirmans, 1996).

While some results proved accurate in TOD and smart growth policies, variables such as the average value of a private dwelling, and the average household income rose to a greater extent throughout the city as opposed to selected TTC areas. Such an increase is opposite to traditional theories (Bae et al., 2003; Oreskovic et al., 2009). While an overall rise in living costs can be attributed to inflation between 1981 and 2006, the increase in variables throughout the city oppose to areas surrounding Sheppard Line 4 may be a result of policy change over the 25 year period.

As outlined in Table 4**,** the City of Toronto has experienced a significant loss of green space both within the study area and larger city as a whole. Within the City, environmental space has been defined into five categories: shore and deep water, light, medium and deep vegetation. Within the selected TTC areas a decrease of 81% is observed, compared to 49% in the larger city. This loss of green space represents a challenge to environmental sustainability (Banai, 2005). The loss of green space appears to have largely been replaced by urban/impervious space. leThe City of Toronto employs a number of environmental considerations when planning to ensure the cities natural environment is protected. As per the Toronto Official Plan:

- S3.4 The natural environment will be protected by promoting growth in locations that are supported by transit to ensure energy consumption reduction.

Moreover, the City of Toronto has developed an environmental plan that complements the range of environmental considerations outlined in the Official Plan. Five broad policy objectives aim to ensure the continued protection of Toronto's environment:

1. Protect environmental capital;
2. Prevent air, land and water based pollution;
3. Reduce the consumption of natural resource;
4. Restore regeneration green space processes; and,
5. Integrate environmental variables when city-building decisions are being made.

While numerous policies and reports have been drafted outlining the protection of green space and environmental features within the city, the protection of such features have appeared to be placed second to that of urbanization and city building. The wide spread urbanization and the removal of green space between 1981 and 2006 is not uncommon as the city's population grew by 17% within that timeframe adding increased density, new settlements, transit lines and overall citywide expansion**.**

In the case of Toronto, modest shifts in variables produced a situation where the relationship between the development of Line 4 and a change in economic, social, and environmental variables is conclusive. In comparison to results experienced in Metropolitan Vancouver, a modest shift in intensification was also identified between the 1991 to 2001 timeframe in Toronto (Ashley et al., 2010). Throughout the GTHA, a total of 44%, or 131,491 persons were settled through intensification efforts. The remainder 56% of growth occurred in greenfield sites. With this in mind, findings produced in my research align with the urban growth boundary identified in the 2010 Growing Cities Neptis Report on the basis that Toronto is considered a hybrid case. The Toronto case moderately accepts that a relationship is present between the development of transit and shift in identified variables is present, which on the ground likely represents some development on Sheppard Avenue, likely at Yonge Street (e.g., development around Yonge-Eglinton would have likely show a stronger correlation between transit and urban development).

Moreover, in accordance to Walks (2008), much of the extreme shifts in socioeconomic variables, referred to as gentrification, occur within the downtown core of the city. As the TTC study area falls within the peripheral areas, a relationship between modest shifts in socioeconomic variables is drawn. The findings of both this research and Walks (2008) align on the basis that the larger processes of urban growth were indeed identified within the City of Toronto, however to a much lesser extent within the TTC study area.

In the case of Toronto and the selected TTC areas, the null hypothesis is accepted arguing that there is a difference between variables within the 800-meter study area when compared to the city constant between 1981 and 2006. These differences confirmed that development of Sheppard subway Line 4 has created demographic and economic growth around the selected stations.

Metropolitan Montreal

This section presents the census analysis along a Société de transport de Montréal (STM) area in the region of Metropolitan Montreal to measure which variables, and to what degree have changes between the 1981 and 2006 time period.

The study areas within Metropolitan Montreal produced unconventional transit-oriented development and smart growth results. While some indicators argue an increase in typical smart growth and TOD variables, most argue unconventional results. Such an outcome proves that no or minimal influence is placed upon the development of transit between 1981 and 2006 to measured variables (i.e., the alternative hypothesis is accepted in the case of Metropolitan Montreal).

Context

Metropolitan Montreal is the second most populous area in Canada. The Mille-Iles River is home to low-density suburban municipalities followed by a dense core. This physically separates all areas. Metropolitan Montreal was deemed suitable for this research as it possesses a higher order rapid transit system, and is considered a major economic region. Such criteria allow for the availability of data and research already available throughout the region. The Société de transport de Montréal (STM) is the regional transit authority for greater Montreal providing access to public transportation throughout the region.

Metropolitan Montreal was analysed assuming an area consisting of multiple cities. These cities include: Montreal, Laval, Longueuil, Terrebonne, Repentigny, Brossard, Saint-Jérôme, Blainville, Dollard-des-Ormeaux, and Châteauguay (Government of Canada, 1981, 2006).

Metropolitan Montreal Transit Agency

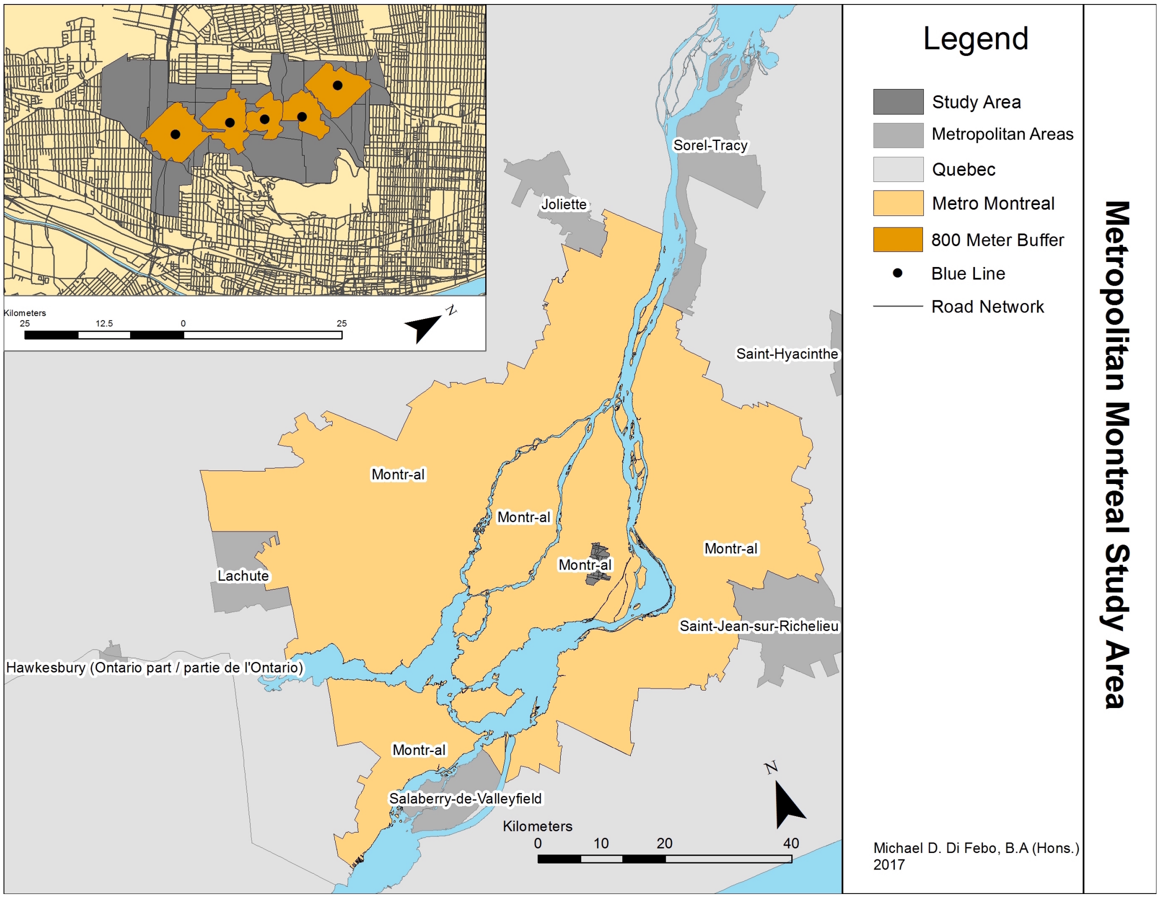
The Société de transport de Montréal (STM) accounts for the majority of public transportation trips in the direct and surrounding Montreal region. STM operates numerous transportation lines throughout the entire region allowing for individuals to travel efficiently. STM has outlined a comprehensive report regarding how the organization is expected to develop an enhanced transit system by 2020 (Société de transport de Montréal, 2012). It is outlined that increased ridership will be directly attributed to new transit investment and system wide updates. Such network improvements will directly influence surrounding neighbourhood characteristics as transit services improve. STM outlines six priorities, strategies and actions they hope to achieve by 2020. Out of the six, three priorities drive the necessity to study economic development and transportation in Montreal:

(1) The expanding of services throughout the region;
(2) The continued improvement of the systems performance; and
(3) To ensure sustainable development is centered at all future expansion decisions.

The entire Montreal Metro system is approximately 70 kms long operating over 68 stations on four subway lines. The entire system adopts a 1,425 mm standard electrified gauge system. This allows for trains to travel at an approximate average speed of 40 kms/h and reaching top speeds of 70 kms/h (Société de transport de Montréal, 2016).

This research measures a specified portion of the Blue Line as the construction and completion of the below noted subway stations fall within the 1981 to 2006 time period. The section of line measures approximately 4.1 kms long and similar to Vancouver and Toronto, my analysis of Metropolitan Montreal focuses on five subway stations along the Blue Line: Outremont, Edouard Montpetit, Université de Montréal, Côte des Neiges, and Snowdon. Figure 7 outlines the Metropolitan Montreal study area both at the city and STM scale.

Figure 7: Metropolitan Montreal - Study Area



Source: Michael D. Di Febo

Social and Economic Analysis

Table 5 presents raw census data for 1981 and 2006 and the rate of change. Cells highlighted in bold depict entries that are greater between the study area and regional values. Data have been classified into social and economic variables. Where required, the average of variables was calculated. Variables outlined in the rate of change analysis produce unconventional results as to what TOD and smart growth argue (Canadian Urban Transit Association, 2004; Curtis, 2008). Traditional results should show a significant increase in density and all economic variables, however, this was not the case within Metropolitan Montreal.

The region experiences a greater increase in population density, the average number of rooms per dwelling, and average gross monthly rent. Average household income, one of the sole variables typically measured in TOD and smart growth remained the same within the study area compared to the larger region (Ram, 1988). A discussion pertaining to why such changes have occurred, and an in-depth analysis of the results are outlined below.

Table 5: Social and Economic Indicators for Metropolitan Montreal and Selected STM Areas, 1981 and 2006

Census Periods		1981		2006		Rate of Change (%)	
Variables		Areas					
		Metro Montreal	Selected STM Area	Metro Montreal	Selected STM Area	Metro Montreal	Selected STM Area
Social Indicators	Population	2828349	118429	3634105	118392	22%	0%
	Population Density	659.0	7401.9	846.7	7399.5	22%	0%
	Average # persons per household	2.7	2.3	2.4	2.3	-13%	0%
Economic Indicators	Average # of rooms per private dwelling	4.98	4.99	5.6	5.1	11%	2%
	Average value of private dwelling	64754	105301	256228	415715	75%	75%
	Average gross rent (monthly)	290	374	667	827	57%	55%
	Average household income (Annual)	23114	28502	63611	79878	64%	64%

Environmental Analysis

Table 6 provides insight into the amount of green space during the 1981 and 2006 time periods for both Metropolitan Montreal and the selected STM areas. The value represents the amount of green space within the study area and throughout the entire city as a percentage. Figure 8 outlines the set of satellite imaging used to produce the above noted values.

Similar to Metropolitan Vancouver, inconsistencies in data pertaining to *the addition of green space* have been noted between 1981 and 2006. This has not been the case with the urbanization occurring within the 25 year time period of Metropolitan Montreal. Such inconsistencies are attributed to unsatisfactory satellite imaging and high cloud cover collected from the Landsat 3 probe. As such, a secondary analysis is conducted identical to that of Metropolitan Vancouver. A comparison adopting 2006 satellite imaging that depicts the percentage of environmental space within the study area compared to the rest of Metropolitan Montreal. Moreover, Table 6 also outlines the secondary environmental analysis for Metropolitan Montreal. Hydrology and vegetation have been classified as environmental features and is represented as an entire percentage for the area.

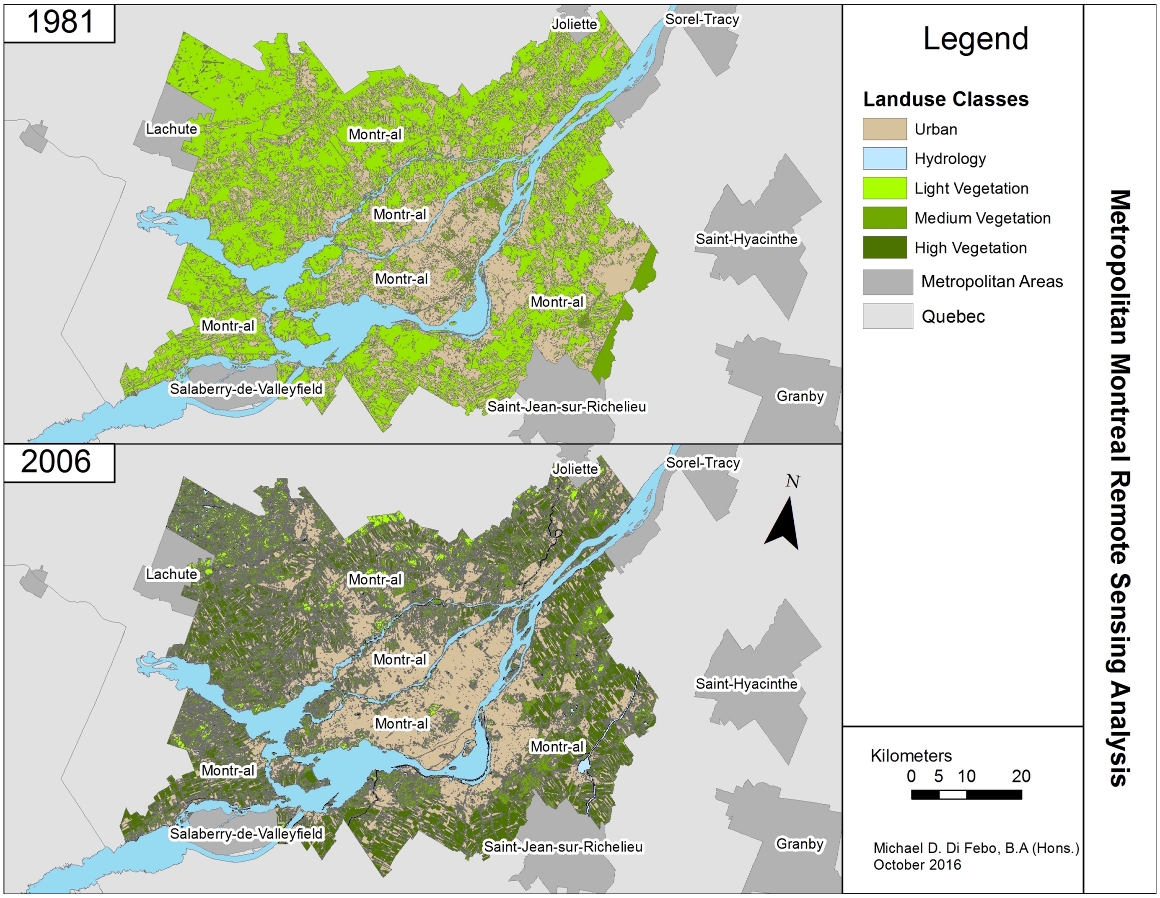
Table 6: Green Space in the Metropolitan Montreal and Selected STM Areas in 1980 and 2006

Census Periods		1981		2006		Rate of Change (%)	
Environmental Variables		Areas					
		Metro Montreal	Selected STM Area	Metro Montreal	Selected STM Area	Metro Montreal	Selected STM Area
Primary analysis	Open Space (in km^2)*	2631 km^2	2.5 km^2	2668.5 km^2	5 km^2	1%	50%
Secondary analysis	Hydrology coverage (%)	--	--	1%	0.04%	--	--
	Vegetation coverage (%)	--	--	38%	33%	--	--
	Urban coverage (%)	--	--	61%	67%	--	--
	Total coverage (in km^2)*	--	--	4291.0 km^2	15.0 km^2	--	--

Note: The primary analysis uses km^2 as a unit of measurement and has been rounded to the nearest 0.5 km^2 while the secondary analysis uses a percent change.

Figure 8 outlines the imaging used in the additional analysis to measure hydrological, vegetation and urban coverage in 2006. Here too, the scale of the images makes it difficult to assess the loss of green space but the following images indicate that vegetation might have matured since 1981.

Figure 8: Metropolitan Montreal - Remote Sensing Study Area



Source: Michael D. Di Febo

Discussion

Metropolitan Montreal produced unconventional results as to what TOD and smart growth theories argue. In a conventional analysis, the development of a transit system should trigger specific variables to increase significantly when compared to neighbourhoods absent from such transit investment. Such variables are typically population density, and economic variables referring to average dwelling value, and average monthly rent values (Boyce et al., 1974; Robert Cervero, 1994; Lin and Gau, 2006). These social and economic variables in conventional planning theory change with the influence of transportation development.

In the case of Metropolitan Montreal, the population growth and density within the area produces a zero percentage change between the 1981 and 2006-time period. Given the urban expansion that occurred during the noted time period and the early part of the 21st century, a zero percentage change in population density after the development of a transit line indicates the absence of relation between transit development and development. This relation is further expressed no change in average value of private dwelling and average household annual income between the selected area and the rest of Montreal.

Throughout the development of the City of Montreal's Master Plan, sustainable development and growth is amongst its core planning principles. Moreover, the City has adopted a borough basis for the outlining of density and height provisions (City of Montreal, 2004):

- C.2, S2.2 outlines the necessity for integrated transportation networks within the existing and proposed urban fabric;
- C.4: Detail Planning provides a planning analysis of all areas within the City; supplementing,
- P.2: Borough documents outlining building density on an individual borough basis.

Rationale as to why the analysis for Metropolitan Montreal has produced such unconventional results may be that the extension of the Blue Line between 1981 and 2006 to accommodate the need for transit in an area that was lacking. As the existing area was already built up with low-rise residential, land was not available for TOD and intensification/smart growth projects. Hence, the development of this line did not promote real estate development but simply satisfied the need to move people with the immediate existing area having no significant influence on economic, social, or environmental variables.

Through visually interpreting satellite schemes from the 1986 and 2006 time periods, it is clear that no significant urban development has occurred within the STM study area. Satellite schemes show existing low rise residential in place directly along the expansion of the Blue Line. On this basis, the expansion of the Blue Line served the principle of accessible transit as opposed to transit-generated development and the need to stimulate growth.

Metropolitan Montreal experiences unconventional results as to what TOD and smart growth policies argue. The built environment around the study area saw very minor modifications despite the presence of the subway extension. During the time frame of 1981 to 2006, gentrification rather than intensification occurred in specific areas, most specifically downtown core (Walks, 2008). Intensification along transit areas would occur later in metropolitan Montreal, notably in surrounding municipalities of Laval and Longueil, two areas that are notably outside the STM study area (Filion and Kramer, 2010). As Filion and Kramer (2010: 2243) remarks, intensification is occurring "around public transit stations, but without ascribing to these transit-oriented developments (TODs) the features of nodes," which is in part explained by job and housing stagnation.

While the primary remote sensing analysis was unattainable due to inconsistent results and a high degree of cloud coverage in satellite imaging, the secondary environmental analysis was conducted for 2006. Likewise to Metropolitan Vancouver the percentage of urban space, hydrology, and vegetation was compared within the study area to the rest of the city. Results indicate that the similarities between the two areas are close, Table 6. In the case of Metropolitan Montreal, the selected STM areas present a slightly higher 67% of vegetation compared to 61% for the rest of the city. This is directly attributed to the urban make-up of the city core. In the unique case of Montreal, a large portion of the downtown benefits from the open and forested areas of Mount-Royal Park. Moreover the University of Montreal, which makes up a significant portion of the selected STM study area, contains a significant proportion of green space. Provided these facts, it is reasonable to acknowledge that the downtown STM study area contains a higher percentage of green space due to its proximity to park and other green areas. Numerous sections through the City's Master Plan emphasize the goals of protecting the environment:

- C.2, S1 outlines the requirements for a high quality living environment;
- C.2, S2.5 outlines the requirement to link architecture and urban landscapes together;
- C.2, S2.6 outlines the need for an enhanced archaeological and natural heritage; and,
- C.2, S2.7 outlines that a healthy environment is one of the primary goals of the City's Master Plan.

Once again, the notion that the downtown study area contains a greater proportion of green space is not typical that of urban sprawl and smart growth theories. Higher order transit lines are typical in being within areas of high densities, downtowns, promoting condominium development, and a high ratio of urban space (Handy, 2005; Huang, 1996). Hence, this presence makes way that Montreal is an unconventional and alternative case when compared to the previous two cases analysed.

Noting the above analyses, the alternative hypothesis is accepted within the region of Metropolitan Montreal. There is no significant difference between the measurements of variables within areas directly adjacent to transit hubs oppose to the city as a whole between 1981 and 2006. Nor is there evidence proving that in the case of Metropolitan Montreal, relationships exist between variables and theories pertaining to smart growth, TOD, or sustainable development. This acceptance of the alternative hypothesis raises question on the direct correlation between transit development and smart growth principles (Downs, 2005). An observation is that the development of the Blue Line has had a minimal influence on the surrounding neighbourhood in terms of social, economic or environmental change due to its construction being an infill project (in a context of limited demographic and economic growth, and political independence debates) as opposed to serving a new development projects.

Conclusion

It is widely accepted that public transportation has influence the economic and social development, and the provision of environmental spaces to varying degrees. This research proves that this is not always the case and that such influence varies on a case-by-case basis. In this research, seven variables in terms of economic, social, and environmental were identified to track the degree of change experienced in a specific study area compared to the rest of the city. Two separate methodologies were developed for this research. A statistical method was used to extract and calculate rates of change based on Canadian Census information. The satellite imaging was used to identify patterns of hydrology, vegetation, and urban space followed the calculation of vegetation cover. In two of the three case studies, the Landsat imaging was unacceptable for use due to inconsistencies in data. In such cases, a secondary analysis was performed to calculate the percentage of vegetation cover within the study area and in the rest of the city in 2006.

Metropolitan Vancouver, the City of Toronto, and Metropolitan Montreal possess unique characteristics as three of the top populated cities in Canada (Government of Canada, 2011). These characteristics have influenced patterns of transportation development and settlement. Each city is unique in the development of policy that has governed the way the regions have grown between 1981 and 2006. This research focused on growth from the perspective of transportation, specifically transit (Metrolinx, 2008; Société de transport de Montréal, 2012; TransLink, 2008). While the development of light-rail transit, subways, and higher order rapid transit was prioritized in some areas, the adoption of commuter rail or rapid bus systems was prioritized in others. This prioritization in varying types of transit has altered patterns of development that have changed the of economic, social, and environmental variables.

Metropolitan Vancouver, the City of Toronto, and Metropolitan Montreal are all classified as economic metropolis regions as per Statistics Canada (Statistics Canada, 2006). Regardless of this commonality, policy changed influence each of the three regions differently and cannot be translated to others based on their classification through Statistics Canada.

A number of limitations were present in this research. Quantitative research limitations may originate from the highly dependent nature and reliability on coders and codes used during data collection (Holsti, 1969). While it is always tricky to compare metropolitan areas given their different characteristics, it is even more tricky to do so based on only quantitative data. There are many social, historical and political processes influencing growth that might elude quantitative data collection. Change throughout all three-study areas may have been influence to some degree by the adoption or implementation of urban planning policies. This research did not analyse the introduction or enforcement of policy within the 1981 to 2006 time period. Moreover, due to the quantitative nature of this research, the programming or quantitative classification of regional policies were not considered into the methodology.

An additional limitation was the absence of environmental data and the adoption of Landsat data to measure environmental change or change in green space. As many of the satellite probes used in the research are decades old, many of the instruments and tools used for remote sensing techniques are out-dated when compared to present day technology (United States Geological Survey, 2016d). While dated, Landsat 2, 3 and 5 data provided satellite imaging for the study area and provided full metadata transparency via the United States Geological Survey Earth Explorer satellite imaging data base program (United States Geological Survey, 2016a). Metadata outlines the date, time of photo, spectrum, pathway, row, probe, and most importantly, the percentage of cloud coverage for all imaging. As experienced in the Vancouver and Montreal cases, while satellite imaging was available, a percentage of cloud coverage and aging imaging within the 1981 time period hindered the full completion of the remote sensing methodology. Under these limitations, the remote sensing analysis and calculations should be handed minimal influence on the overall impact associated with transportation development and environmental variables.

An additional limitation arose with the development of the methodology, in terms of data and the classification of sustainability. As previously mentioned, with no universal acceptance of 'sustainable development' variables selected were on the basis on data availability as per the Canadian census. Whether sustainability can be successfully measured, or is even measurable, is a key question that was brought out throughout this research. Findings throughout this research may argue that limited environmental data raises serious question on how to measure or compare the three dimensions of sustainability and even questions the importance given to the environmental aspect in sustainability and sustainable development. Moreover, due to absences in environmental data from the late 20th century, identifying a sole 'environmental variable' became difficult.

Moving forward, it is recommended that recent data sets and variables be selected due to data availability. By analyzing recent data a full range of economic, social, and environmental variables are available proving a true measurement of sustainability. Data sets such as Air Quality Index, the National Household Survey, the Canadian Census, and the Transportation Tomorrow Survey are available if such a study adopted a post 2000 time frame.

In the future, alternative study areas may be defined from cities in Canada that possess higher order rapid transit systems in the way of light-rail or bus-rapid transit routes. For example, the City of Ottawa's public transit system was developed as a bus-rapid and light-rail-transit system. The City of Calgary operates the CTrain an advanced light-rail transit system carrying approximately 300,000 passengers per weekday (Calgary Transit, 2016; OC Transpo, 2016). Alternatively, exploring examples from the United States may also prove suitable due to the abundance of higher-order rapid transit systems and the availability of data.

It is hoped that this research will encourage further exploration into the field of TOD, smart growth and their link to sustainability on a quantifiable basis. Specifically, the link between how TOD is being used in regions to promote and encourage the sustained developments of cities from the economic, social, and environmental understanding. Moreover, as new census data is collected and made available, this research may be carried out once again to either cement or disprove the three mentioned hypotheses and associated outcomes based on a multiple decade rate of change analysis applying Landsat 8 and the 2016 national census data (Statistics Canada, 2016; United States Geological Survey, 2016).

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