SUSTAINABLE URBAN MOBILITY PLANNING FOR MISSISSAUGA

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Executive Summary

Public transit is becoming increasingly necessary in cities. City of Mississauga is currently experiencing a high car mode share (about 85 percent), but significant efforts have been made towards achieving efficient public transit. To improve the current situation, Mississauga's Transportation Master Plan 2019 targets to reduce car usage by increasing the share of sustainable transport trips to 50 percent by 2041.

Research and Findings

The purpose of this study is to identify the existing factors driving the car mode share in Mississauga. The study further attempts to identify priority zones where policy interventions can support the City's sustainable mode share target. The literature suggests that Density, Diversity, Design, Transit Service, and Socio-Economy largely impact mode choice decisions. A set of variables corresponding to these five indicators are assessed in this study. The research suggests that high-frequency transit, land use mix, employment opportunities, and high population and job density are favorable to incentivize public transit use. To identify the key variables driving the car mode share of Mississauga, a series of multiple regression analysis are performed. The key findings include:

- Population density and Transit service indicators (high-frequency bus services, transit availability indicator, and bus and GO station catchment) are statistically significant predictors of car mode share for work-related origin trips. Increase in one high-frequency bus stop per square kilometre is expected to decrease car mode share by 2 percent;
- High frequency bus stops density, retail density and job accessibility are negatively related to car mode share for destination work trips;
- Availability of high-frequency bus service and population density are statistically significant variables in non-work origin trips. With an increase in a population density of 1,000 people per square kilometre, it is expected that the car mode share will decrease by 5.76 percent for non-work origin trips;
- Population density, bus and GO station coverage, and Walk Score are statistically significant and negatively related to car use for non-work destination model.

Recommendations and Policy relevance

It is recommended that Mississauga increase the presence and frequency of transit services and consider providing feeder services to GO stations in the identified intervention areas. This study finds that, to minimize the usage of cars, transit services are not the only consideration. Transit must be complemented with improvements in zoning, land use, employment density, and population density. This is especially important in parts of southern Mississauga along the GO transit corridor, where interventions to allow high density housing, employment, and land-use mix will facilitate a transit-supportive environment. In addition to the land use interventions, the city needs to focus on improving the built form of the high-density areas to foster a more conducive environment for pedestrians and cyclists. An active transport friendly built environment can play a major role in promoting transit as a mode choice

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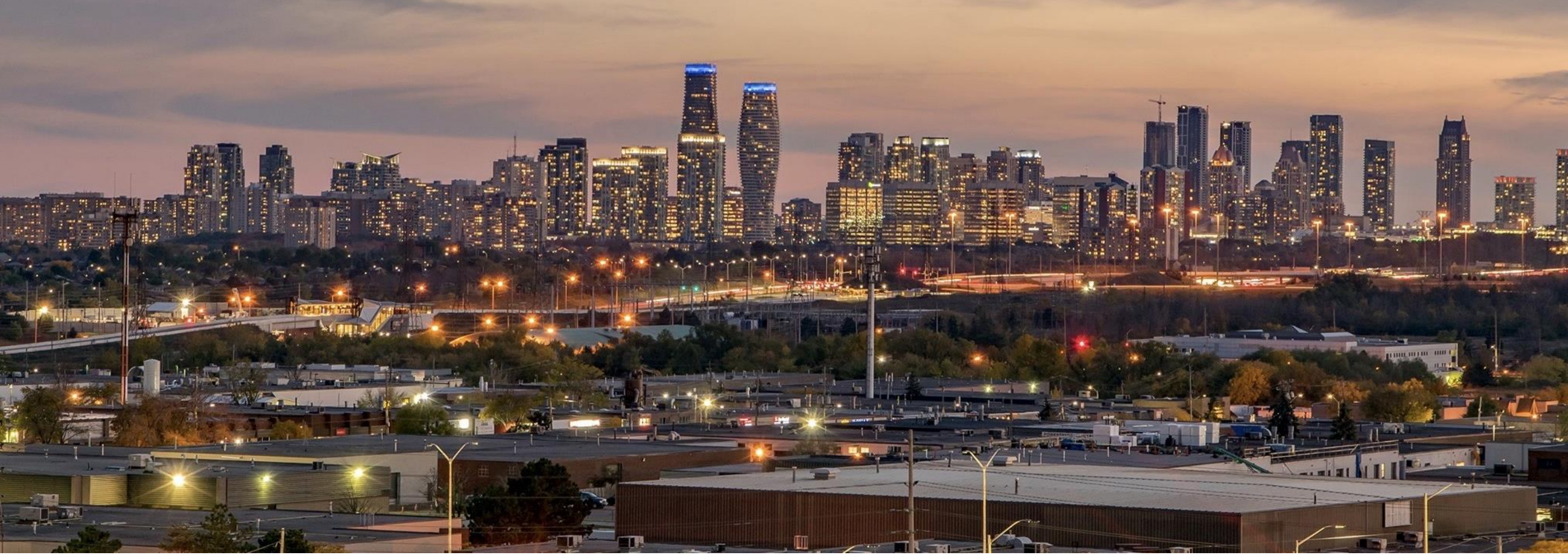


1 Introduction

Many recent transport plans and strategies in Canada focus on reducing car dependency (City of Vancouver 2012; Region of Peel 2019; The Big Move 2008). This goal is induced by several crucial needs of mobility, including but not limited to tackle the issues of congestion, emissions, social equity, and needs of the aging population (Lindsay et al. 2010). It is anticipated that increased investments in new infrastructures will reduce the car usage. Research in recent years has also highlights the importance of multiple factors that influence the mode choice decisions (Foth et al. 2013). Studies indicate that mode decisions are driven by various factors including land use and built form, personal preferences, and socio-demographics (Limtanakool et al 2006; Badoe and Miller 2000; Owen and Levinson 2015).

Like other major Canadian cities, the City of Mississauga plans on reducing the current state of the car dependency. The commute in the City of Mississauga primarily depends on Cars as about 85 percent of the total internal and external trips are made by cars (TTS 2016). To improve the current situation, Mississauga's Transportation Master Plan (TMP) 2019 targets to reduce the usage of cars and increase the share of sustainable transport trips to 50 percent by 2041 (City of Mississauga 2019). The residents of the City of Mississauga show lower auto dependence compared to most other municipalities in GTHA in terms of vehicle ownership (Statistics Canada 2016). Considering the potential of becoming a less car reliant city, it is important to identify key factors influencing the current mode choice in Mississauga and plan to improve it in the future.

1.1 Research Question:

- How are the current sociodemographic factors and built form influence the mode choice of work and non-work trips in Mississauga?
- What are the areas falling behind on indicators to achieve the sustainable transport (walking, cycling & transit) and

what type of interventions can help reduce the car dependency?

1.2 Methodology

The main objective of this research is to identify the existing factors driving the mode choice, establish priorities and advise policy interventions supportive of the City's Transportation Master Plan (TMP). The study includes a review of the City of Mississauga's TMP objectives, followed by an assessment of best practices around the region and leading world cities in achieving the sustainable mobility goals. The study uses series of mode choice indicators derived from literature to assess the current mode choice in different areas in the city. Further, low performing areas in terms of active and transit mobility are identified using statistical analysis between different indicators and the current mode choice. The analysis will help to identify priority zones and actions, thus guiding the effort to improve the land use-transportation integration in the City of Mississauga. The methodology used for the study follows three major steps.

Step 1: Understanding the Context and Mode Choice Indicators

With an overview of important mode choice factors in general and in the GTA context, the study draws on the most prevalent and effective indicators of transportation-land use mode choice from the literature review. In order to assess the current car dominance in Mississauga, the factors are clubbed together to frame broad categories influencing the current mode choice decisions. Further, applications by neighbouring municipalities are examined to identify the key considerations in successful mode choice redistribution.

Step 2: Impact of the variables in the context of Mississauga

From the literature review the study consolidates a list of indicators using statistical analysis to characterize and assess different areas in Mississauga. A model is developed for each type of Origin-Destination trips: The model is used to analyze the primary mode of one-way trips considering Mississauga TAZs as origin and destination. The analysis further identifies statistically significant factors which encourage or discourage the mode choice decisions.

Step 3: Recommendations and Way Forward

The results of the statistical models are then used to identify priority traffic analysis zones. Suitable interventions are proposed in line with the goals of the City's TMP to improve the current land use and transportation scenario and reduce the car dependency. Proposals outlines the policy level recommendations to address the planning issues affecting the identified zones. Although the proposed interventions in this study might focus on certain areas and reflect the needs of the identified character areas, but the interventions can also be applied to other areas in the city having similar characteristics.

2 Literature Review

This chapter attempts to provide an understanding of the current strategies and initiatives of Mississauga which provide sustainable mobility solutions. Different strategies adopted by neighbouring municipalities and other world leaders to reduce car-based trips are also reviewed. Finally, literature on predominant factors affecting the mode choice in general is discussed and suitable indicators are identified for the city of Mississauga.

2.1 Mississauga Transportation Strategies

Over the past decade, Mississauga and Region of Peel have proposed multiple strategies to improve the current transportation system by reducing the usage of personal vehicles. This section summarizes some of the official documents that capture the needs of improved current mobility and discuss relevant strategies adopted by Mississauga:

Mississauga Transportation Plan (2019)

The plan provides an assessment of the current of the transportation system of Mississauga and offers suitable strategies for the short, medium, and long term. It highlights that currently, of the total trips made (to, from, or within Mississauga on the average weekday), 85 percent are by car, 11 percent are by transit, and only 4 percent are by walking and cycling. The plan envisions to bring down the share of car trips down to 50 percent by 2041. To achieve this goal along with others, the plan highlights the need to conduct multiple studies to provide specific interventions to achieve its target.

Mississauga Cycling Master Plan (2018)

This plan emphasizes on fostering a cycling culture in Mississauga by creating an overall cycling network of up to 900 kms and improving the cycle parking infrastructure. In 2016, only 0.6 percent of overall trips in Mississauga were covered by cycles as a primary mode. The plan also highlights the need to develop a bicycle share system to address the first and last mile gaps of the transit. Further, the plan discusses the need to promote cycling culture by introducing cycle promotion and marketing programs in schools and communities.

Mississauga Official Plan (2015)

The plan considers transportation as one of the prime concerns and aims to create a multi modal transportation network for the city. It states that “Mississauga’s local transportation system will focus on the day to-day travel needs of those who live, work or play in Mississauga and will increasingly emphasize opportunities for transit and active transportation.” The official plan promotes active transportation and development of Community Nodes to reduce the car dependency. Further, the plan emphasizes on supporting transit networks through compact, pedestrian oriented, mixed land use development of suitable nodes, mobility hubs and corridors. The plan also emphasizes on the improving the design of the current transit corridors and reducing dedicated parking spaces.

Region of Peel Long Range Transportation Plan (2019)

The regional plan outlines some robust initiatives to achieve its ambitious goal of 50 percent sustainable mode share by 2041. The plan calls for an increased public transit modal share as its main objective, and specifies that “It is the Policy of the Regional Council to encourage area municipalities to achieve a minimum 20 percent Peak Period modal split for transit within the urban system served by transit by the year 2021.” The plan also includes the provision of bicycle and pedestrian opportunities while designing roadways and the emphasize on creating a bicycle network in coordination with adjoining regions and municipalities. A policy to encourage ridesharing is coupled with the proposed development of a High Occupancy Vehicle network.

Region of Peel Sustainable Transportation Strategy (2018)

The plan provides a framework to address the Region’s goal of achieving a 50 percent sustainable mode (walking, cycling, transit, carpooling and telework) share by 2041. The plan builds on the framework of the region’s Active Transportation Plan 2012, and other existing plans of the concerned municipalities and stakeholders.

Hurontario/ Main Street Corridor Master Plan (2010)

This plan provides various strategies and interventions for the Hurontario/Main Street corridor (deemed one of the most important north south axis of the Peel Region), integrated planning for rapid transit, intensified land use and enhanced urban design. The plan proposed to link the Urban Growth Centres of the region, while bringing together five Mobility Hubs, which are also the identified locations of future inter-regional transit connections and enhanced transit-oriented development (Big Move, 2008). The corridor has a distinctive urban character and is important to all the policy documents discussed above.

Summary

The City of Mississauga’s Transportation Master Plan serves as the primary reference for the City’s strategic position on transportation issues. In alignment with the provincial and regional objectives, the City of Mississauga understands the need to opt for a sustainable mode choice practice as outlined in multiple policy documents. The City aims to foster a cultural shift to encourage residents and employees of Mississauga to use active transportation.

2.2 Transportation Strategies of Other Neighbouring Municipalities

Ministry of Transportation Ontario (MTO) provides a vision to reduce car dependency at a provincial scale. In its Sustainability inSight vision document, MTO aims to increase the sustainable mobility using following strategic goals:

- Increase accessibility by improving mobility, choice, and safety
- Integrate transportation and land-use planning to reflect sustainability
- Optimize infrastructure design, capacity, and investment
- Drive a cultural shift towards sustainability

In alignment to this vision, different municipalities across Ontario have made several attempts to cater to the current mobility challenges, an overview is discussed below:

Toronto GTHA

The Greater Toronto and Hamilton Area (GTHA) is one of the fastest growing regions in North America with anticipated population growth of 41 percent between 2016 and 2041. The GTHA Regional Transportation Plan (RTP), 2041 envisions "To have a sustainable transportation system that is aligned with land use and supports healthy and complete communities." In an initial attempt to improve the regional transport in GTHA, The Big Move 2008 plan helped identify multiple regional transit projects and provided the foundation of the Regional Transportation Plan (RTP). The RTP aims to achieve a transit mode share of more than 14 percent from the current 5 percent and increase active mode share by 2.2 percent during the peak periods. The outcomes of the plan are anticipated through the improvement of the current transit infrastructure, increasing frequent rapid transit routes, improving job accessibility, doubling the regional cycling network, and reducing overall travel time.

City of Hamilton

Hamilton was able to achieve several transportation milestones since the 2007 Transportation Master Plan, including implementation of smart commute program, local & regional transit projects, advanced traffic management system, bicycle share program, and formulating active transportation plans. However, Hamilton face a few crucial challenges including lack of sustainable funding for transportation infrastructure, changing demographics, slow adaptation of new technologies and slow pace of shifting the mode share to sustainable modes. In 2007 TMP, Hamilton mentions to bring down the single occupancy vehicle usage from 68 percent in 2001 to 58 percent by 2011 but failed to achieve its target as only one percent shift was realized. The 2018 TMP, therefore, sets out a revised policy framework for improved results. The new focus area of the plan includes improved research on demand modelling, facilitate complete streets, improve accessibility, integrate new technologies, prioritize active transportation, and promote sustainable mode alternatives.

York Region

York is facing increased urbanization in the form of low-density residential communities supported by vast employment opportunities for workers around the region. With the goal of providing a convenient, accessible, and equitable service to all the residents of York, the region emphasizes the importance of urban design to minimize the walking distance to transit stops and optimize park and ride facilities. The implementation of an intermodal regional rapid transit network is one of the key achievements of the York Region. As per TTS 2016 report, the automobiles are still the most popular mode of travel as 78 percent of total trips are made using personal cars. Although, the car share has dropped by approximately two percent since 2001. Simultaneously, the transit and active transportation shares in 2016 have increased by three percent and one percent respectively compared to that in 2001.

Region of Durham

The Region of Durham's Transportation Master Plan, 2017 aims to improve land use and transportation integration by providing better mode choice options, increasing transit ridership, and providing favorable active transportation opportunities. Through strategic network promotions, the region of Durham sets a target to achieve a region wide sustainable mode share of 37 percent by 2031 from the current 30 percent. The idea is to shift most of the auto trips on regional transit. Durham proposed a multifaceted approach to improve its current mode share using following key action points:

- Develop Transit Oriented Development (TOD) Guidelines, and collaborate with regional transportation agencies to ensure the successful implementation of Regional Express Rail
- Implement a comprehensive Rapid Transit system and high frequency networks with integrated the walking and cycling access
- Design improvements at intersection and transitions to encourage active transportation and improve land use mixing & employment distribution

Promote high quality walking and cycling connections to major transit facilities and collaborate with partners to develop and implement programs for promoting sustainable mode choices

Region of Halton

The Region of Halton Transportation Master Plan 2011 aims to promote alternatives to single occupant automobile use through optimizing the road network and dedicating the roadway space to prioritize transit, pedestrians, and cyclists. Although the document discusses the policy ideas to improve the current mobility by encouraging people to use transit and active transportation, the details of the strategies are predominantly conceptual and are limited to the acknowledgment of the need for improvements in these sectors.

Summary

Most of the neighbouring planning agencies have visions and goals like the City of Mississauga. As a common practice most of the cities are planning and investing in transit services and active transportation.

Some of the municipalities are more successful than others in promoting public transit and active transportation, but most are still progressing towards their goal of achieving sustainable model share. The key strategies proposed by these cities include reducing dedicated space for cars, improving multimodal integration, promote active transportation, and creating a more comprehensive public transportation network.

2.3 Policies and Strategies of Global Leaders

For this study, a list of globally recognized cities in sustainable mobility is compiled from SOOT Mobility Ranking, 2015, and Deloitte City Mobility Index, 2019. Although the mentioned Canadian cities are not amongst the best in the word, they are mentioned here due to their contextual relevance (Refer Table-1).

Table 1: Leading global cities for sustainable mobility

Cities	Mode Share (Percent)				Sustainable Mobility
	Car	Public Transit	Walking	Cycling	
Toronto (CMA)	68	25	5	2	32
Montreal (CMA)	69	23	4	2	29
Vancouver (CMA)	67	23	7	3	33
Vienna	27	39	28	6	73
Zurich	30	39	26	5	70
Berlin	32	27	28	13	68
Brussels	47	28	21	4	53
Copenhagen	29	28	7	36	71
Madrid	30	39	30	1	70
Barcelona	27	39	32	2	73
Singapore	29	44	22	1	67
Hong Kong	7	88	3	2	93
Beijing	28	36	27	9	72
London	26	49	20	5	74
Bogota	14	36	46	4	86

Data Source: Statistics Canada 2016, SOOT Mobility Ranking 2015, and Deloitte City Mobility Index, 2019

Vancouver – The Canadian Innovator

Vancouver is selected due to its recent achievements in bringing down the car usage and policy innovations in achieving better active mode share. By 2040, City of Vancouver plans to increase the trips made by foot, bicycle, and transit to two thirds of its overall trips. This target will increase the total number of trips by sustainable modes significantly, while slightly bringing down the motor vehicle volumes. The city's recent panel survey indicates that the mode share target of more than 50 percent trips by transit and active means is being achieved so far. Vancouver prioritizes on changing people's perception about the mode choice and focuses on a range of context specific strategies. It provides strategies to include all demographic groups and sets out realistic targets in the shorter terms. Supported by a dense downtown and transit supportive zoning, Vancouver also has an added advantage of a better climate for active transportation compared to other Canadian cities. Various programs encouraging people to adopt sustainable mode, discouraging single occupancy vehicle usage, and improving transit infrastructure is helping Vancouver to reduce the car dependency.

Vienna – The Leading Follower

Vienna reduced its car trips share from 40 percent to 27 percent, between 1993 and 2014 (Vienna Urban Mobility Plan 2025). A combination of U-Bahn, S-Bahn, tram, and bus network covers the entire city with multiple options of public transportation. An affordable integrated fare system is also deemed very helpful in reducing the car usage in Vienna. Vienna's shift to sustainable transport is a result of long-term vision, innovative pilots and consensus amongst political groups and stakeholders. Vienna may not have been the first city to introduce new transportation policies, but it has thoughtfully tested successful policies from other similar cities (Buehler et al. 2017). Although, Vienna's approach to new transport policies appear time intensive, it had higher probability of success due the practical experience and learnings from other cities. Vienna' phased implementation of new policies, especially the pilot projects, proved to be beneficial while implementing large scale and city-wide interventions. Vienna also conducts periodic surveys before and after studies, measuring the measuring the effectiveness of the implemented policies, thus providing targeted guide for future modifications (Buehler et al. 2017).

Copenhagen – The City of Cyclists

Copenhagen is a compact city, where most commuters prefer active modes of transportation. With about 450 kilometres of cycling lanes and innovative parking strategies for cyclists, Copenhagen is one of the most cyclable cities in the world. In public transportation sector, Copenhagen Metro is known for service availability and customer satisfaction, as it is one of the first 24/7 driverless metros in the world. The metro system, buses and taxis are wheelchair friendly thus making the transportation system accessible for all. At present, of the total commuter trips in the city, only 26 percent are made by cars, while cycles account for about 49 percent of the total trips. Copenhagen has made continued interventions to achieve its current state and it has been a “cycling city” for many years. The city has built at least one mile of cycleway every single year from 1912 to 1969, followed by a greater building spurt between 1975 and 1985. As per the “Cyclist Priority Plan 2017-2025” a continued expansion of the bicycle infrastructure is necessary for the city. Copenhagen aims to further reduce its motor-traffic by reducing car parking spaces and expanding parking spaces for cyclists.

Hong Kong – The PT City

Hong Kong has a well-connected transit system and stands amongst one of the lowest car dependent cities. While facing many challenges in the past on prioritizing funding in the transport sector, the city always moved forward with investing in better infrastructure for transit and active transportation. Transport hubs were created to better integrate surrounding land uses with transport nodes to promote more walking and cycling. Central to the success of this model is high-density urban development that is closely integrated around the transit system. The Transit-Oriented Development initiatives with integrated urban and transport planning ensuring financial sustainability at the same time. Hong Kong has created an accessible, efficient, convenient, and affordable public transportation system. The city uses accessibility-oriented planning strategies, which covers 75 percent of the population and 94 percent of workplaces under a kilometre of the transit stations. In Hong Kong, the provision of public transit is also supplemented by heavy taxes on vehicle ownership to discourage use of personal vehicles.

Bogotá – The BRT Leader

The capital city of Colombia, Bogotá, has a population of around 7 million and has suffered at the hands of an inefficient and congested transport system in the past. To resolve the previous issues, Bogota introduced a Bus Rapid Transit (BRT) system, the Transmilenio, in 2000. Implementation of the BRT system in Bogota helped address issues of road safety, pollution, public transport inefficiency, and sustainability. Transmilenio has helped the city of Bogotá cut its carbon emissions, whilst substantially improving the city’s transport system (Gilbert, A. 2008). The successful BRT has also improved transport links to low income communities. With room for further improvement Bogotá’s BRT provides an excellent example of low budget equitable public transportation system to the rest of the world.

2.4 Factors Influencing Mode Choice

The impact of built environment and demographic factors on transportation mode choice has been a focus of numerous studies. While some of the studies report that the built environment has a significant impact on travel behaviour notwithstanding residential self-selection (Frank and Pivo 1994), others find user preferences and demographics important (Crane and Crepeau 1998).

Multiple studies analyze a range of built environment factors influencing the mode choice but, the three core dimensions of built environment the 3Ds i.e. Density, Diversity, and Design impact travel mode choices to a large extent (Cervero and Kockelman, 1997). Density is defined as interest per unit of area and could be measured as population, employment, or dwelling unit density. Whereas diversity is a measure of different land use and its concentration in any given area. Design includes various physical and social aspects such as street infrastructure, walkability, pedestrian, and cyclist perception etc.

In addition to 3Ds, Ewing and Cervero, 2010 found additional 2Ds i.e. Destination Accessibility and Distance to Transit as important additional determinants of mode choice. The study indicates that that availability of transit services in proximity and destination job accessibility affect transit use at both the origin and destination. Further the mode choice decision is partially driven by socioeconomic status. A public transit equity study found that low-income and minority groups are often captive riders of public transit systems (Garrett & Taylor, 2000). The following subsections discuss different types of indicators to identify those most relevant to the context of Mississauga.

Density

Multiple studies on travel behaviour include density as a potential factor in individual transportation choices (Ewing and Cervero 2010; Zhang 2004). Studies have found a positive association of population and job densities with the usage of transit and non-motorized modes (Cervero 1994; Handy 1996; Ewing and Cervero 2001; Frank and Pivo 1994). Some of the studies also suggest that density itself may not be the driver of mode choice, but the other factors that go along with the density contribute towards it, for instance, travel cost, travel time or job accessibility (Crane and Crepeau 1998; Badoe and Miller 2000). High density often implies reduced vehicle ownership and better transit services, which reduce travel time using transit as compared to auto (Kitamura et al. 1997). Several studies have also observed that critical density thresholds exist beyond which individuals are likely to shift modes of transportation (Frank and Pivo 1994; Ewing 1997; Holtzclaw et al. 2002; Dunphy et al. 2004).

Frank and Pivo (1994) observed significant correlations between employment density and walking & public transit use at the census tract level in the Central Puget Sound area of Washington State. They found that both job density at the destination and population density at the origin play a significant role in influencing mode choice decisions. Similar results by other studies indicate the importance of employment densities at destinations and population densities at origins (Ewing and Cervero 2001; Chatman 2003). Further, higher population density at origin encourages the use of walking, cycling, and mass transit for commuter trips, while higher population density at destination matters for both work and non-work trips. Higher job density at the origin is insignificant for both work and non-work trips while higher job density at the destination promotes cycling, walking, and mass transit for work trips but not for non-work trips (Zhang 2004).

Diversity

Land use diversity has stronger explanatory power over travel behaviour than the urban density (Badoe and Miller 2000; Kockelman 1997). A concentrated land use mix integrated with the transit station can improve off-peak ridership, optimize parking spaces, and increase accessibility of services to residents (Krizek 2003). Some studies indicate that an increase in land use diversity can increase the likelihood of an individual to undertake a home or work trips by walking, bicycling, or transit (Frank et al. 2008; Buehler 2011; Forsyth et al. 2008). Studies have also found that an increase in utilitarian walking and bicycling can significantly be influenced by an increase in the land use diversity (Heinen et al. 2010; Nielsen et al. 2013; Rajamani et al. 2003).

One of the most extensively used metric to measure land use diversity is the entropy score (Shannon 1948), an area-based indicator that measures the degree to which different land uses are evenly distributed (Frank et al. 2004). Kockelman (1997) shows a significant relationship between mean entropy and both vehicle miles travelled and the choice to walk or cycle. The Simpson's Diversity index is also popular as a pattern measure of evenness in land use research (Ritsema van Eck and Koomen 2008; Forsyth et al. 2008). Voorhees et al. (2009) used Simpson's index at a one-half-mile network buffer to examine the relationship between neighborhood design and nonmotorized travel. The index estimated the sum of squares of the area of different land use within the designated area, which weights dominant land uses more effectively than secondary uses (Ritsema van Eck and Koomen 2008). Additionally, walkability indices such as Walk Score® can also be useful to account local land use characteristics and complementarity (Walk Score®, 2011). While not explicitly measuring land use mix, retail counts and essential service points (fresh produce stores, groceries, and pharmacies) can provide an idea of the number and intensity of opportunities available in an area. Retail count exhibit statistically significant elasticity with public transit trips in studies conducted in North America (Ewing and Cervero, 2010, Cervero and Kockelman, 1997).

Design

Design schemes make destinations more accessible and convenient for pedestrians and cyclists (Cervero and Kockelman 1997). A good street network design with well-connected, pedestrian friendly streets encourage people to walk and cycle as a mode of transportation (Dunphy et al. 2004). Studies indicate that pedestrian activity varies according to neighbourhood design factors if density remains constant (Hess et al. 1999). Ewing and Cervero (2010) suggest intersection densities as indicators of neighbourhood design. Their meta-analysis indicates that intersection density has one of the highest elasticities for walking and public transit trips. Studies by Forsyth et al. (2008) and Cervero & Kockelman (1997) suggests that the proportion of four-way intersections is symbolic of a well-connected built environment, with a statistically significant relationship to walking and non-motorized trips. Acknowledging the importance of intersection density, the MTO recommends a minimum intersection density of 0.6 intersections per hectare to ensure connectivity between local destinations (MTO 2012). Although, Cervero and Kockelman (1997) found limited correlation between non-work travel and pedestrian-oriented design, individuals living in areas with a grid street pattern with lower parking allowances were found to have lower vehicle kilometer travelled (Forsyth et al. 2008).

per unit area (Forsyth et al. 2008; Ewing et al. 2004). Street density reflects the connectivity of the built environment as well as the amount of space allocated to the public right of way in a designated area. Additionally, the availability of parking space also affects a person's choice to commute via public transit. A commercial space or transit station surrounded by vast parking lots discourages usage of active modes (Renne 2008). Therefore, the design of commercial space and transit stations must be sensitive to the needs of the potential users. The presence of pedestrian paths, placement and size of parking facilities are some of the key indicator of urban design affecting mode choice.

Transit Service

It is believed that availability of transit service affects transit use at both the origin and destination (Chakour & Eluru, 2013; Lindsey et al., 2010). Several variables are found in the literature to demonstrate transit service availability. These include distance to commuter train stations, station density, station catchments, and service frequency.

As existing literature suggests that the ability to walk to a transit station incentivizes transit use (Lindsey et al., 2010; Moniruzzaman & Páez, 2012; Murray & Wu, 2003), we use catchment areas of the transit stops as variable to measure this threshold of walkable access to the bus and GO stations. The final variable associated with transit availability is service frequency, which alludes to the quality and convenience of local transit (Taylor et al., 2009). Overall, it is known that transit service directly affects job accessibility and the ease of completing first and last mile trips (Lachapelle et al. 2011).

Socio-Economy

In addition to the built environment and transit services, it was also found in the literature that socioeconomic profile of a population also impacts mode choice decisions (Foth et al., 2013; Pasha et al., 2016; Taylor et al., 2009). It was also found that due to the high expense of vehicle ownership, transit use by low income, immigrant, or unemployed groups is high in many cities (Foth et al., 2013; Ong & Miller, 2005). Therefore, it is expected that an increase in the financial factor, for instance, a high-income neighbourhood with a large average family size, will exhibit higher car use, as these communities tend to opt for the perceived convenience of the car. This is especially true in high income suburban communities, where alternative modes to the car are limited. Conversely, with a concentration of recent immigrants and unemployment, we expect comparatively lower car usage, as these marginal groups often lean on public transit in response to a unique set of financial barriers (Taylor et al., 2009).

The relation between travel behaviour, built environment, and demography suggests multiple indicators can be used to predict travel behaviour. While their level of complexity and relevance varies considerably, the indicators tend to fall within Ewing and Cervero's 5D's framework. However, it is evident that the urban form characteristics considered in these studies are associated with more sustainable mode choices. Characterizing planning decisions based on these indicators may lead to better land use and transportation planning in case of Mississauga.

Table 2: Variables identified for assessment

Variables	Description
Density	
Pop Density	Population per sq. km
Job Density	Employment per sq. km
Accessibility to jobs by Car	Job Accessibility Under 60 minutes by Cars
Diversity	
Entropy Score	Entropy Score (usage of three consolidated land use categories i.e. i. residential, ii. Retail, commerce, and institutional, iii. Open space and recreational)
Simpson's Index	Simpsons Diversity Index (usage of three consolidated land use categories i.e. i. residential, ii. Retail, commerce, and institutional, iii. Open space and recreational)
Retail Points Density	Points of Interest Retail shops per 1000 people
Essential Service Points	Essential Service points (grocery, fresh food, and pharmacy) per 1000 people
Walk Score	Walk Score of the Analysis Area centroid
Proximity Indicator	Proximity to basic services and amenities formulated by Statistics Canada
Design	
Street Density	Street Length per sq. km of the Analysis Area
Intersection Density	Intersections per sq. km of Analysis Area
Transit Service	
Transit Availability Score	Public Transit Service Proximity Index formulated by Statistics Canada
Bus Station Coverage	Catchment of Bus routes in the Analysis Area
GO Station Coverage	Percent of Character Area covered under a kilometre radius of GO Transit Station
High Frequency Bus Service	Number of Buses with frequency under 20 minutes
High Frequency Bus Service Catchment	High Frequency Bus Service Catchment of the Analysis Area
Socio Demography	
Vehicle Ownership Rate	Percent of households with vehicle ownership
Neighbourhood Index	Neighborhood Quality of Life Index formulated by Region of Peel
Household Size	Average number of persons living within a single household
Low Income Population	Percent of population falling under the Low-Income category as per the LIM-AT measure

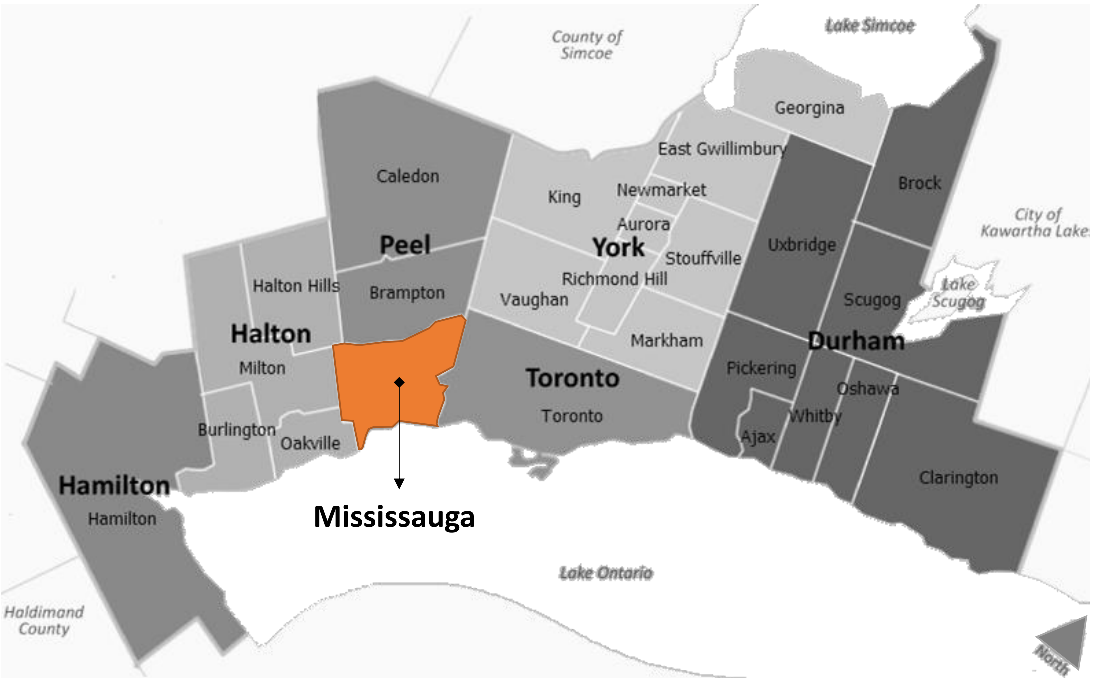
3 Data and Methodology

3.1 Study Context

This study focuses on understanding the determinants of car mode share trips originating or terminating in Mississauga for work and non-work purposes. Mississauga is Canada's sixth most populous city, located on the waterfront of Lake Ontario. Mississauga shares its boundaries with Toronto in the east, Region of Halton in the west, City of Brampton in the North, and Lake Ontario on South. With a population of 721,599 in 2016, Mississauga is the second densest city in Ontario with an average population density of about 2,467 people per square kilometre (Statistics Canada, 2016).

Canada's busiest airport, Toronto Pearson International Airport, is in Mississauga located in the northeastern part of the city. The city is served by a network of arterial roads and regional and national highways, including Highways 401, 403, 410, 409 and Queen Elizabeth Way. Besides, the city has access to Highway 427 along the eastern edge and Highway 407 along northern edge. Several transit agencies including the MiWay, Metrolinx serve Mississauga providing transit services (Bus Service, Bus Rapid Transit, GO Transit). The Toronto Transit Commission and the Brampton Transit also provide connections from neighbouring cities to Mississauga.

Figure 1: City of Mississauga in the context of GTHA



3.2 Methodology

This study uses a series of variables derived from literature to assess car mode share trips made both to and from each Traffic Analysis Zone (TAZ) in Mississauga for work and non-work purposes. Further, key mode determinants are identified using a cross-sectional multiple linear regression analysis. For this regression model four types trips are assessed: (1) origin car share for work; (2) destination car share for work; (3) origin car share for non-work; and (4) destination car share for non-work. The origin car share for work and non-work trips refer to the proportion of trips originating from the analysis areas with cars as a primary mode. Conversely, destination car mode share trips refer to the proportion of car trips terminating in the analysis areas. The trips analyzed in the analysis includes both home and non-home based trips.

Figure 2: Mode Share of Mississauga TAZs as origin and destination for work trips

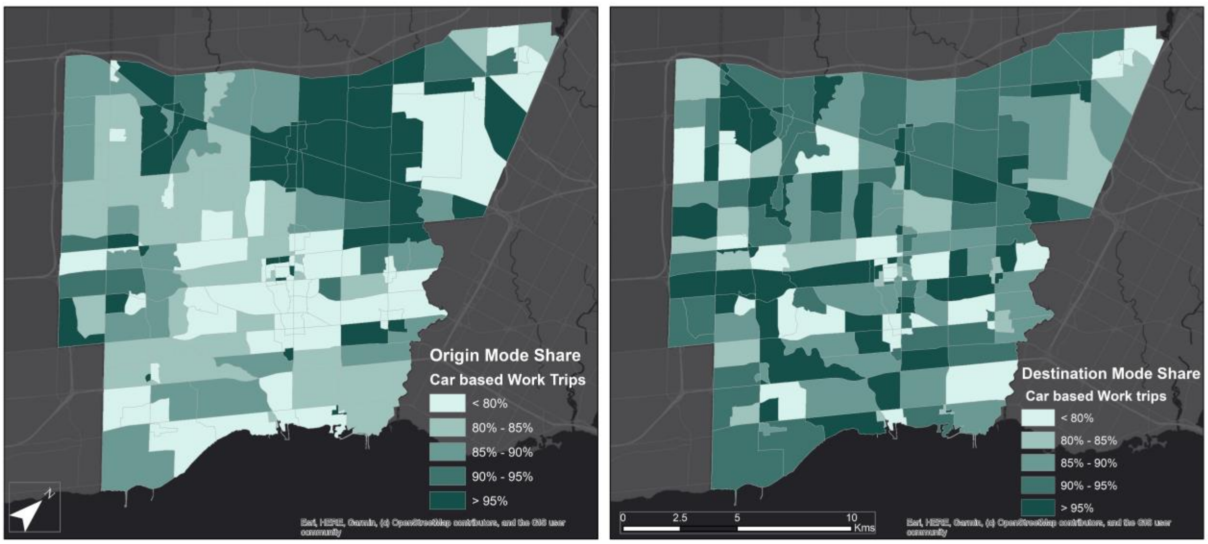
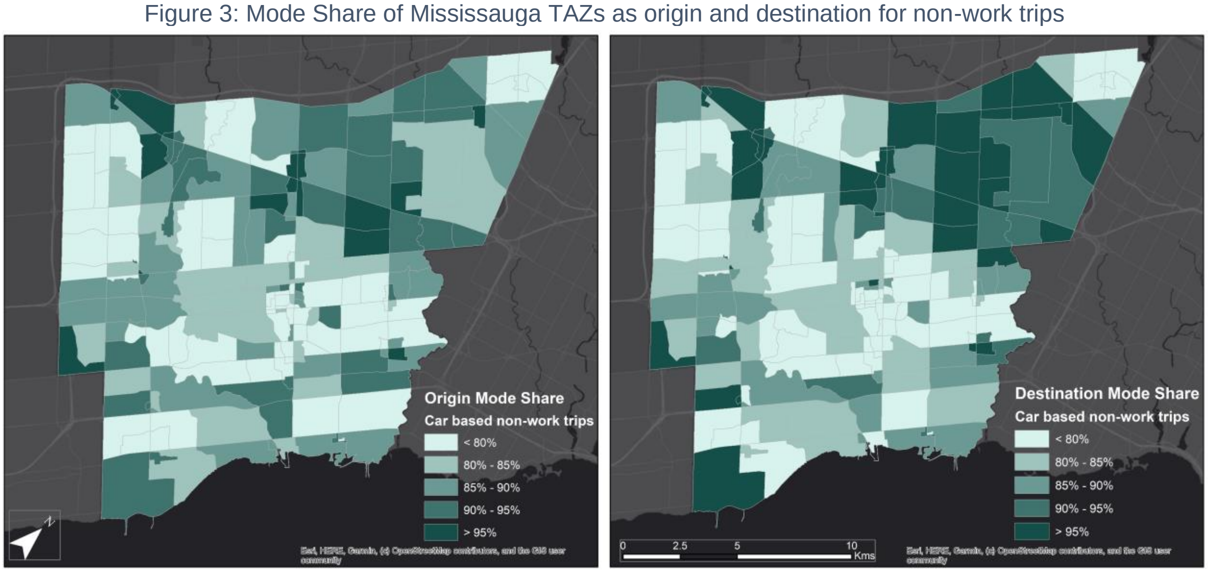
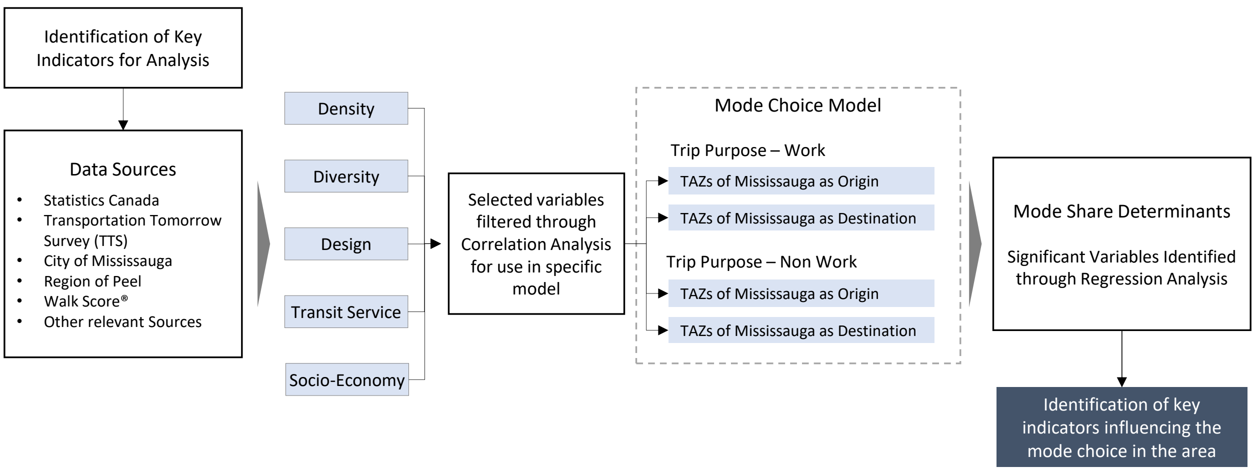


Figure 3: Mode Share of Mississauga TAZs as origin and destination for non-work trips



Based on the literature, a total of 20 independent variables were identified to be tested against car mode share. To identify the relevant variables for origin and/or destination model, a correlation matrix was used. The highly correlated variables can significantly skew the results of a regression. Therefore, any two variables with a correlation greater than |0.55| were not included together in the model. The following figure indicates the methodology flow used to identify the variables influencing mode share:

Figure 4: Methodology flow



The dependent variable in the regression models is the proportion of car-share trips originating and destined in TAZs for work or non-work purposes. To determine the magnitude of the impact of different variables on car mode share and to understand whether these variables vary by origin/destination and trip purpose, four multiple linear regression models were created. The first two models test the origin and destination car mode share trips made for work purpose. Whereas the last two models test the car mode share trips for non-work purposes.

These models provide statistical significance of the tested variables along with the magnitude of their impact on the current mode share. Finally, the statistically significant factors, encouraging or discouraging the mode choice decisions, are identified. These factors are assessed for TAZs to provide small and/or large-scale interventions.

Similar analysis is also performed for Character Areas (CAs), details of which is provided in the Appendix A. The analysis of the CA level is helpful to formulate larger scale interventions.

3.3 Data

Every five years, the Transportation Information Steering Committee (TISC) conducts travel behaviour surveys of residents of the GTHA called Transportation Tomorrow Survey (TTS). TTS use a mixed sampling approach to maximize the representativeness of the data. In TTS, respondents are asked about their personal and household travel characteristics, including origin-destination, mode used, trip length and trip purpose. TTS is used in this study to understand the changes in transit mode choice and travel behaviour in TAZs. Table-3 summarizes the statistics of the dependable variables used in the study. For this study, the Census Tract (CT) level socio-demographic data from the Statistics Canada and the Traffic Analysis Zone (TAZ) level travel behaviour data from TTS are used.

Table 3: Summary Statistics of the dependable Variables

TAZ Car Mode Share	Min	Max	Mean	Median	Standard Deviation
Origin Work	0.47	1.00	0.80	0.84	0.22
Destination Work	0.49	1.00	0.88	0.91	0.12
Origin Non-Work	0.55	1.00	0.84	0.85	0.10
Destination Non-Work	0.56	1.00	0.84	0.84	0.10

Table 4: Summary statistics of tested variables

Variable	**Min**	**Max**	**Mean**	**Median**	**Standard Deviation**
Density					
Population Density	142	25,973	3,633	3,025	3,851
Job Density	140	8,787	1,737	1,368	1,535
Car Accessibility	957,960	1,943,841	1,530,150	1,572,881	188,051
Diversity					
Entropy Score	0.00	1.00	0.56	0.62	0.30
Simpson's Index	0.00	0.67	0.37	0.43	0.20
Proximity Indicator	0.00	0.09	0.02	0.01	0.02
Essential Service Points	0.00	86.20	4.90	1.24	10.38
Retail Points	0.00	855.56	55.89	17.59	115.61
Walk Score	0.00	93.60	54.22	53.82	20.76
Design					
Street Density	18.47	5,063.03	175.69	133.15	364.63
Intersection Density	0.00	365.51	79.22	79.35	57.91
Transit Service					
Transit Availability	0.24	1.00	0.71	0.71	0.22
Bus Station Coverage	0.11	1.00	0.77	0.82	0.22
GO Station Coverage	0.00	1.00	0.19	0.00	0.32
High Frequency Bus Service Density	0.00	137.89	10.62	5.72	15.08
High Frequency Bus Service Coverage	0.00	1.00	0.52	0.48	0.32
Socio Economy					
Vehicle Ownership	0.78	0.99	0.91	0.91	0.04
Household Size	2.18	3.90	3.00	2.90	0.47
Low Income Population	0.06	0.29	0.15	0.13	0.06
Neighbourhood Index	31.25	87.67	60.54	63.00	16.02

As mentioned in the previous section, four linear regression models are used to analyze the variables influencing the mode share of TAZs. While some tested variables are present in all models, many are specific to either trip origin or destination as travel preferences into and out of a TAZ can vary significantly. The following table summarizes independent variables tested in these models:

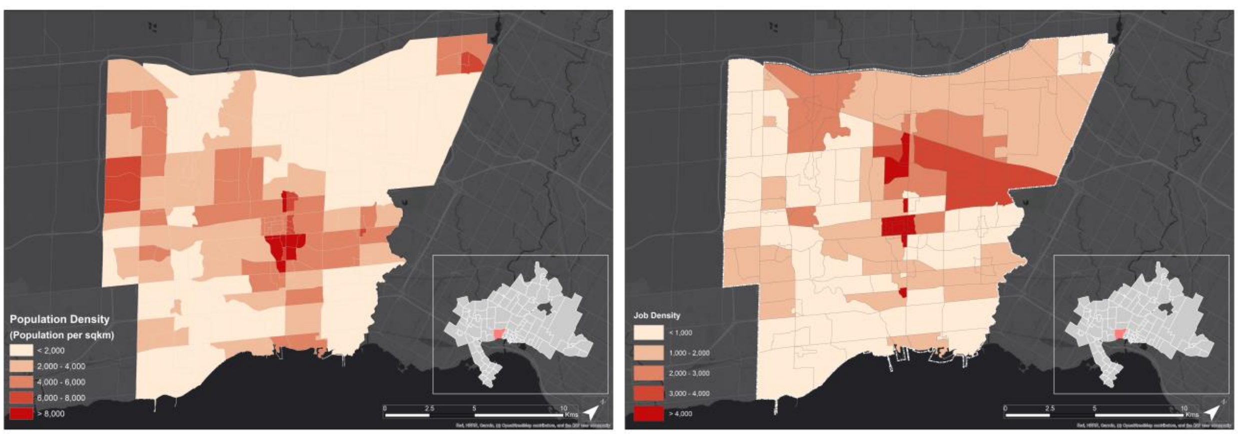
The above-mentioned independent variables (Table 4) are categorized in to five broad categories i.e. Density, Diversity, Design, Transit Service and Socio-economy, details of which are explained in subsequent sections.

Density

Since most of the data acquired is available at the CT level, there is a need to interpret this data at TAZ level to perform the regression analysis. For example, to get the TAZ's population density, the census tract population data is used from Statistics Canada and an intersection analysis was performed in ArcGIS. Similar analysis is preformed to get other relevant data for the analysis.

The figure 5 represents population and employment density, representing that most of the areas have population density fewer than 2,000 persons per sq. km, however, higher densities are seen in downtown and surrounding areas.

Figure 5: Population and Employment Density of Mississauga TAZs

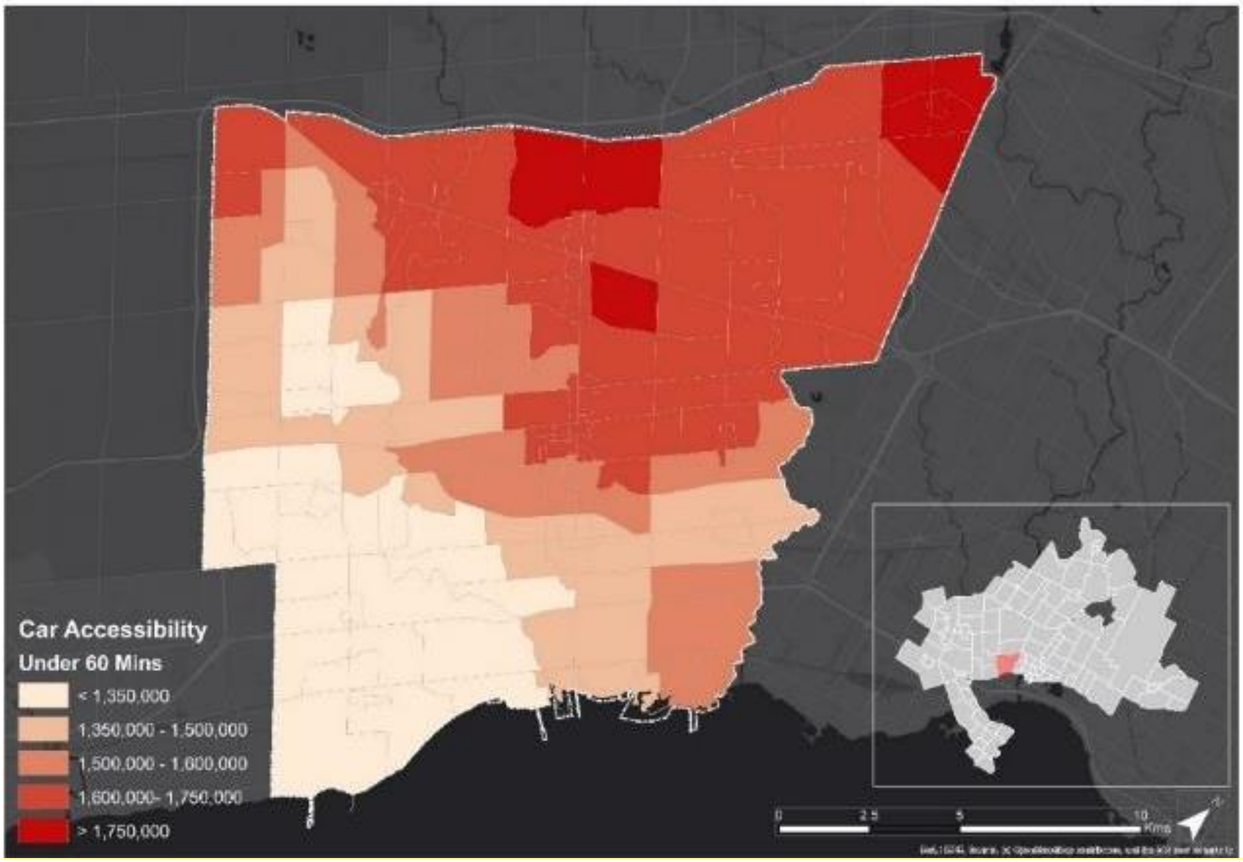


In 2019, with a total of 450,000 jobs, Mississauga had the highest jobs per capita in the entire GTHA. As can be seen from the above map, the Job density in most of TAZs is less the 2,000 jobs per sq. km with higher (>4,000) concentration of jobs present in the downtown and northern parts of the city (refer figure 5). The low job densities reflect longer commute time, it is therefore expected that areas with higher job density and comparatively less commute time will have lower car mode share.\

Evidently, both population and job density are found to be in the lower range in southern parts of Mississauga, which also accommodates Long Branch and Port Credit GO stations. These low-density areas may have greater potential to support higher densities given its proximity to the regional transit.

Another variable assessed is the Job accessibility by cars which evaluates accessible work destinations, and number of commuters who can feasibly use cars to access their jobs. Figure 6 below, indicates that the job accessibility is least (<1.35 million jobs under 60 min) in the south-west part of Mississauga and increase with proximity to the Airport area in the north-eastern part of the city. It is expected that higher job accessibility by cars will result in increased car use.

Figure 6: Job Accessibility of Mississauga TAZs by car



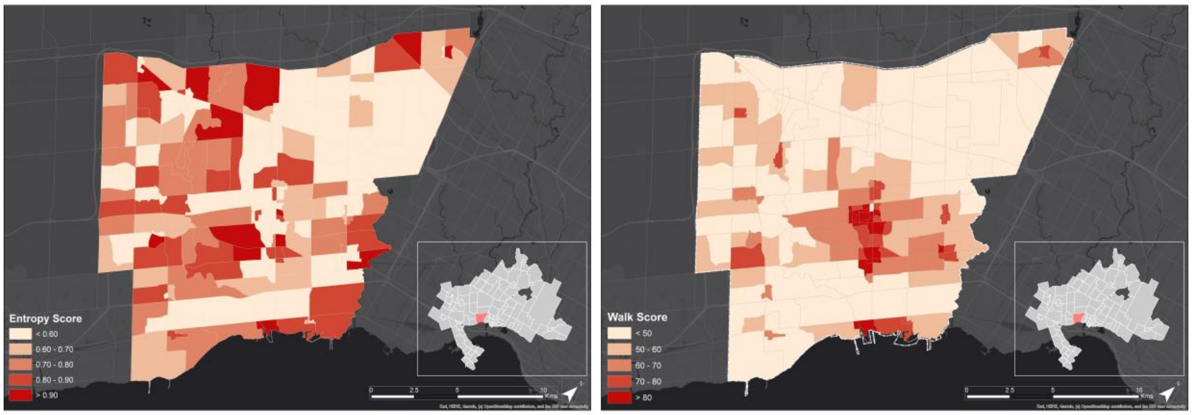
Diversity

For land use diversity measure, Entropy score is primarily used in the analysis due to its better compatibility with other tested variables. The entropy score is defined as:

$$LUM = -1 \left(\sum p_i * \ln(p_i)\right) / \ln(n)$$

where pi is the ratio of each land use classification area to the area of the TAZ and n is the number of land uses considered. Scores fall between 0 and 1, where 1 indicates a perfect land uses mix in each TAZs. In this study, 2016 land use data from DMTI Spatial, Inc. is used. Five land uses were considered, namely residential, commercial, government and institutional, industrial, and parks. Although average entropy score of all TAZs is 0.56 (a low score), Figure 7 indicates that most of the areas have higher entropy. It is analyzed that some of the areas in the city have zero entropy score, thus lowering the average. Literature suggests that area with higher entropy score is expected to have a lower car share.

Figure 7: Entropy Score and Walk Score of Mississauga TAZs



Another variable under Diversity is Walk Score which is estimated by intersecting the postal code-level score data with the TAZs. As indicated in the figure-7 above, most areas have a Walk Score of less than 50, which falls under the category of “Car-Dependent – Most of the errands require a car". However, the areas around downtown and GO transit stations have a better walk score, more than 90 in some TAZs.

Other variables including number of Retail points and number of essential service points are calculated from the DMTI Enhanced Points of Interest shapefile. Essential services points are defined as those with SIC codes 5411, 5431 or 5912, namely grocery stores, fruits and vegetable markets and drug stores.

Design

Two variables are analyzed under Design category – Intersection Density and Street Density. Intersection density is defined as the number of intersections within a TAZ, excluding intersections on expressways. High intersection density provides with more permeability i.e. more opportunities for walking and cycling. Hence it is expected that those TAZs with low intersection density will have a high car share.

Street density measures not only the connectivity of the built environment, but also the amount of space allocated to the public right of way in each area. A streets layer data of Mississauga is intersected with the TAZs to estimate street density. It is expected that a higher street density will negatively relate to the car mode share.

Transit Services

Transit service category includes four variables - Bus station Coverage, GO-station Coverage, High Frequency Bus Service, and Transit Availability. To obtain the catchment area of bus stations and GO-train stations, a service area analysis in GIS is performed to measure the TAZ share covered under the respective transit services. The location and schedule of each bus station and GO station is obtained from General Transit Feed Specification (GTFS) data. GO stations have a larger service area supported by low housing density, and car dependence. These stations therefore attract riders from a larger distance, as ample parking at the stations incentivize driving to transit. Hence a primary catchment of 1 kilometre is considered for the GO Station catchment (refer figure 8).

Figure 8: Bus station and GO station coverage of Mississauga TAZs

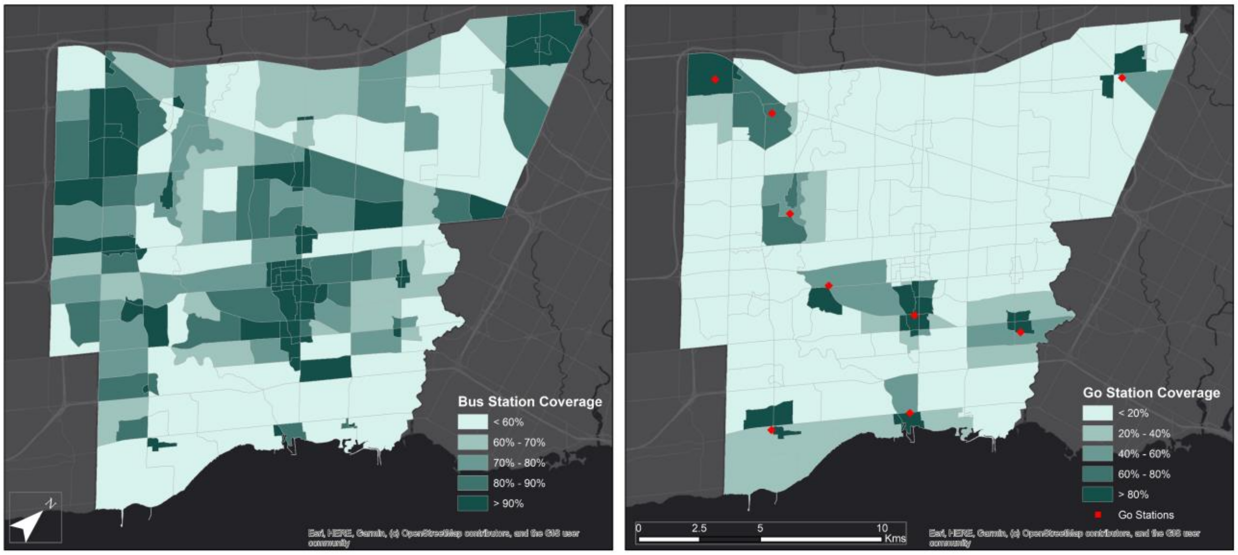


Figure 9: High frequency bus stop catchment of Mississauga TAZs

Literature suggests that TAZs within 1 km or less of the GO stations will see a decrease in car mode share, due in part to the perceived convenience of walking to transit (Morency, et al., 2011).

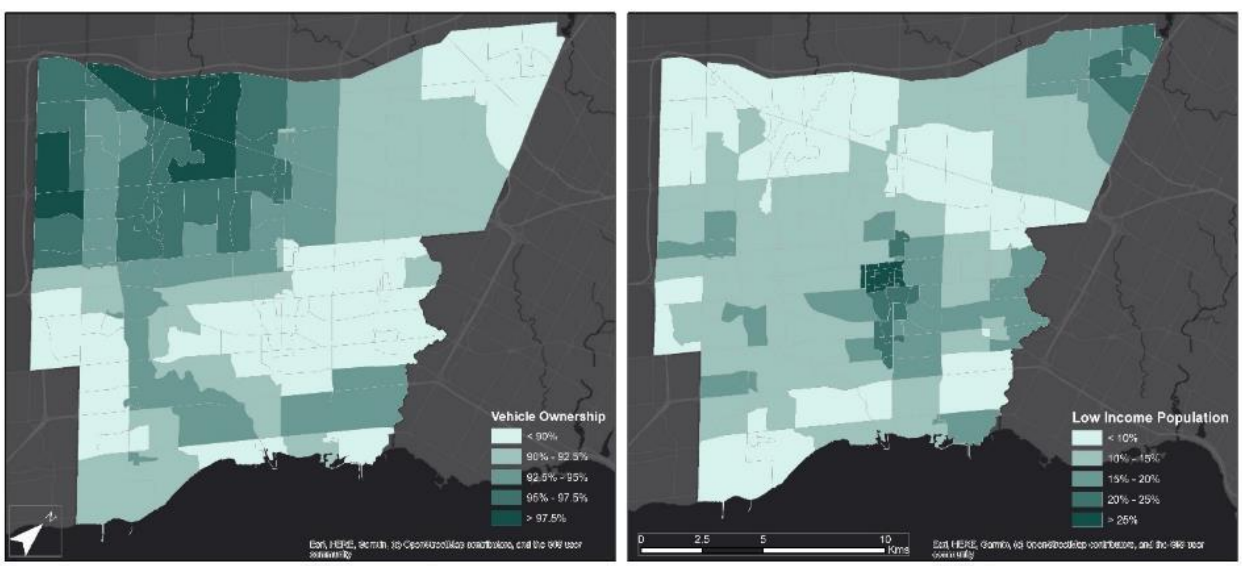
High-frequency bus routes are analyzed to assess the impact of TAZ's proximity to high-frequency bus services (services under 20 minutes) on the mode choice decision. Service frequency alludes to the quality and convenience of local transit (Taylor et al., 2009). Using GTFS schedule and stop times data of all the bus stations in Mississauga, the bus frequency during the morning peak (6 am to 9 am) was determined. The bus frequencies are converted to an hourly average frequency for the analysis area. The data was further intersected with TAZ to estimate the average per-stop transit frequency for each character area in Mississauga. The general bus stop density and presence of high-frequency bus stops can be visualized in the figure-9.

All transit service variables are expected to have a negative relation with the car share. So, a TAZ with high number of high frequency bus-stops is expected to have low car mode share.

Socio-Economy

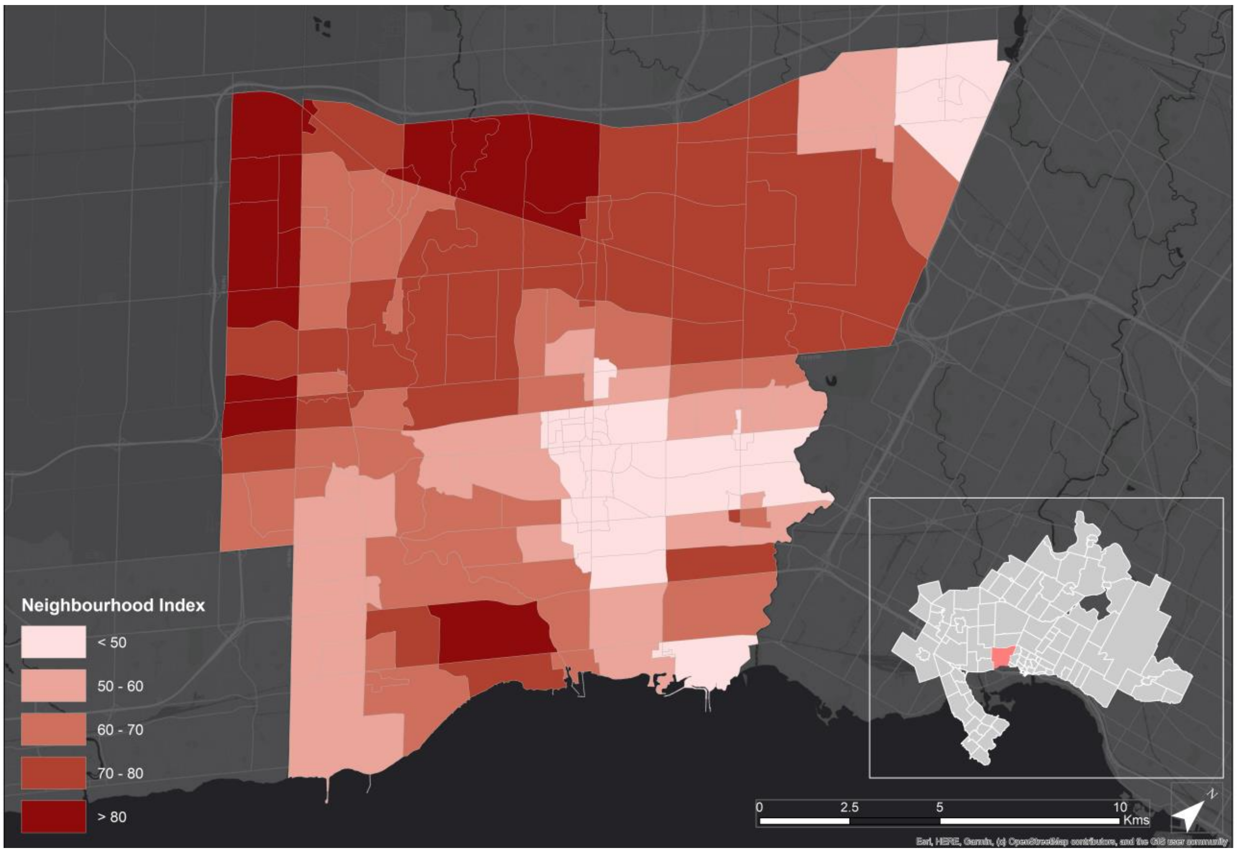
Standard socio-economic variables i.e. income, vehicle ownership, and work status can influence travel behaviour. Due to the expensive vehicle ownership, low income population, immigrants, or unemployed groups tend to rely on public transport. Therefore, it is expected that a high-income area with a large average family size, exhibit higher car use

Figure 10: Vehicle ownership rate and Low-income population presence



The neighbourhood index (Region of Peel, 2016) combines data across domains of neighbourhood well-being to provide a summary of comparative quality of life across different neighbourhoods. The index assesses Census Tracts (CTs) across 6 domains and 21 indicators, which are combined to create a score. The score ranges from 0 to 100, where the higher the score is a representative of a better quality of life. The score was sourced from Region of Peel and further interpreted for TAZs using ArcGIS (Figure-11).

Figure 11: Neighbourhood Index of Mississauga



4 Results and Discussion

The following chapter outlines the impact of each tested variable on origin and destination car mode share. The significance of variables in the regression models suggest, as expected, that car mode share within a traffic analysis zone is motivated by different factors at the beginning and end of a trip. The analysis performed in this chapter suggests that some traffic analysis zones experience a lower car use depending on the characteristics of the population, built environment, and local transit opportunities.

4.1 Car Mode Share for Work Trips

The work commutes in the city of Mississauga are analyzed considering traffic analysis zones as origin and destination, findings of models are summarized in this section:

Origin Model – Work Trips

The analysis of the origin model suggests that, the local transit near home is a statistically significant predictor of low car mode share. The transit service indicators in this model include high frequency bus services (HBFS), transit availability indicator, and bus and GO station catchment. Increase in the density of bus stops having high bus frequency (20 mins frequency) by 1 bus stop per sq. km is expected to decrease car mode share by 2 percent if all other variables remain constant. Density indicators are also associated with outbound car share. With increase in population density by 1000 people per sq. km, the car mode share is expected to decrease by 0.46 percent if all other variables remain constant. The impact of other variables on origin car mode share-work trips, as assessed in origin model is provided in the table 5.

Table 5: Origin Car Mode Share - Work Trips

Variables	Coefficients	t Statistic	Lower Bound (95% CI)	Upper Bound (95% CI)
(Constant)	0.570**	3.189	0.217	0.923
Pop Density	-0.460*	-2.311	-0.852	-0.067
Job Density	2.368**	4.381	1.301	3.434
Entropy Score	-0.062*	-2.479	-0.112	-0.013
Intersection Density	3.187*	2.239	0.377	5.996
Street Density	-0.137	-0.823	-0.465	0.191
Transit Availability	0.164**	3.558	0.073	0.255
Bus Station Coverage	-0.090*	-2.124	-0.175	-0.006
GO Station Coverage	-0.091**	-4.300	-0.133	-0.049
HBFS Density	-2.016**	-2.951	-3.364	-0.668
Vehicle Ownership	0.28.	1.602	-0.065	0.625
HH Size	0.021	1.286	-0.011	0.054
Low Income	-0.435*	-2.496	-0.779	-0.091

* Significance at 95% interval — N - 185 Traffic Analysis Zones

** Significance at 99% interval — R Square - 0.581

Additionally, it was found that TAZs with higher presence of low-income population tend to have less car mode share. Improving financial stability, which relates to household income and the affordability of housing, causes an increase in car use as low income families opt for alternative modes to the car (Chia et al., 2016; Foth et al., 2013; Giuliano, 2003). This suggests that social deprivation, perpetuated by financial and employment barriers, incentivizes the use of public transit as an alternative to private vehicles. It is therefore imperative that commuters with little alternative to public transit be provided equitable service; connecting major low-income employment destinations (Legrain et al., 2015).

The job density portrays an unexpected behaviour as it is positively related to car mode share. The behaviour may be explained by various other factors including easy availability of parking facilities and/or lack of adequate public transit services especially high frequency bus services to the employment zones.

While all the variables were analyzed in the origin model, some were purposely excluded from the results. The walk score and neighbourhood index were excluded as these variables had unacceptably high correlation with other built environment and demographic variables used in the model. Also, the decision to include Entropy score over Simpson's index, essential service points, and retail density was due the compatibility of entropy score with other variables. Variables including the number of transit proximity, car accessibility, high frequency bus service coverage, average trip time, presence of recent immigrants, presence of unemployed population, and vehicle per household were excluded as these variables were either not statistically significant in the model or had high correlation with other similar variables.

Destination Model – Work Trips

The model shows that high frequency bus stops density is statistically significant and negatively related to car use, revealing that high bus frequency service (under 20 min frequency) will decreases the car mode share by 2.28 percent. Similarly, job accessibility is a significant predictor of car mode share. With an increase in 1000 jobs per sq. km, car mode share decreases by 0.1 percent considering all other variables remain constant at their mean. While this coefficient is surprisingly small, it points to the importance of having sufficient jobs distributed across areas to support the local transit service. Additionally, an increase in 10 retail stores per sq. km area will reduce the car usage by 0.2 percent. The retail store coefficient indicates that people are discouraged to use cars if retail stores are available in proximity and they do not have to go out of the way to fulfil their essential needs. The impact of other variables, assessed in destination model, on car mode share-work trips is provided in the table below.

Table 6: Destination Car Mode Share - Work Trips

Variables	Coefficients	t Statistic	Lower 95%	Upper 95%
(Constant)	0.992**	14.823	0.860	1.124
Accessibility Car	-0.102*	-2.189	-0.194	-0.010
Entropy Score	0.015*	0.419	-0.056	0.086
Walk Score	-0.001	-1.780	-0.002	0.000
Retail Density	-0.194**	-3.114	-0.317	-0.071
Proximity Score	1.036*	2.232	0.120	1.951
Transit Availability	0.071	1.986	0.000	0.142
HBFS Density	-2.281**	-4.402	-3.304	-1.259

* Significance at 95% interval
** Significance at 99% interval

N - 194 Traffic Analysis Zones
R Square - 0.345

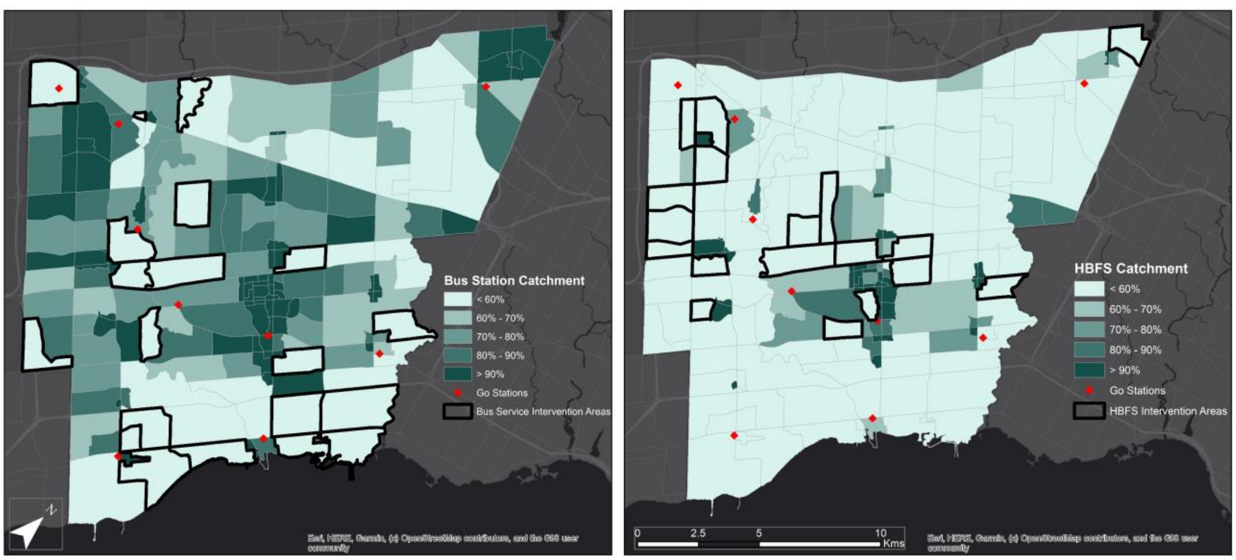
In addition to the variables included in the destination model, several variables were analyzed but excluded from the results. Demographic variables including population density, neighbourhood index, low income group, recent immigrants, household size, and vehicle ownership were excluded due to their association with the location of the trip origin. Other variables such as job density, bus station catchment, GO station catchment, and Simpson's index are excluded due to their either high correlation with other variables or lower significance in the model.

4.2 Discussion of Findings – Work Trips

The results of the origin and destination models for work trips show that the transit infrastructure is relevant to both trip origins and destinations. The high frequency bus stop density is statistically significant in both the models, and therefore supports previous researches suggesting that people are likely to switch to public transit if it can be frequent and reliable at the beginning and end of a trip (Lindsey et al., 2010). However, the statistical significance of service coverage varies between the two models. High bus frequencies and GO station coverage at the origin of the work trips can discourage more people from using cars compared to their presence at the destinations.

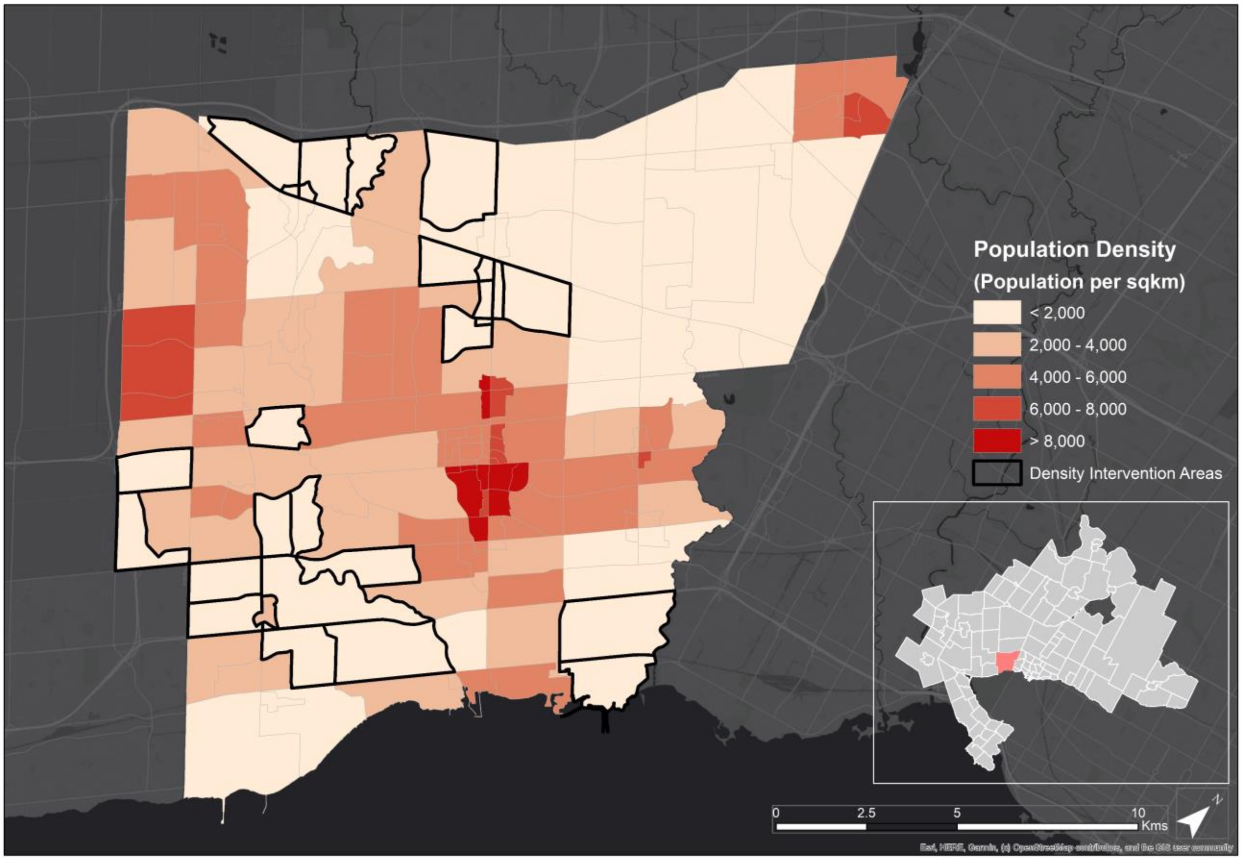
In an attempt to identify some key areas for focused interventions, areas having bus catchment between 40 to 60 percent are prioritize. Further, only those TAZs with population density of more than 1,000 people per sq. km in case of normal bus frequency and more than 4000 people per sq. km. in case of high bus frequency are selected. Using these filters, areas highlighted in the following figure are identified for improvement in bus services to encourage the public transit mode choice.

Figure 12: Bus Service intervention areas



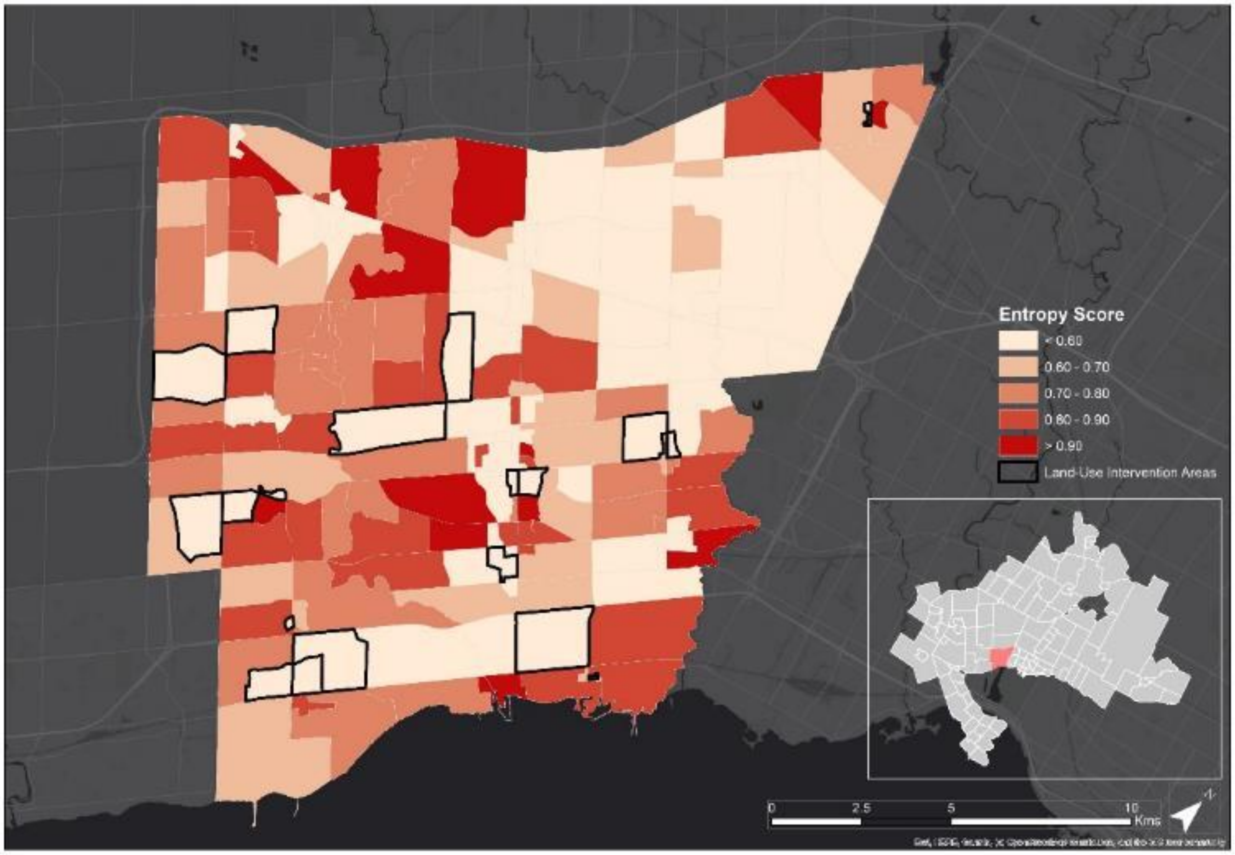
It was found in literature review that population density is a direct and/or indirect determinant of mode share. The results of this study also indicate that the population density is negatively related to car mode share. Hence to achieve a more sustainable mode share, the City of Mississauga needs to prioritize areas to increase the current population density. Therefore, for population density interventions, TAZs with a population density between 1,000 people per sq. km to 2,000 people per sq. km are selected. Further, those areas with car mode share more than 90 percent are identified for population density intervention as indicated in the following figure.

Figure 13: Population Density intervention areas



To incentivize home-work trips by transit, it is important to consider the land use diversity. The study reveals that a good mix of land use, proxied by Entropy score in the model, is relevant to discourage car mode share. This suggests that a diverse land use provides opportunities for trip chaining, incentivizing the transit use and decreasing the perceived necessity of the car (Gutiérrez et al., 2011; Hurst & West, 2014; Lachapelle et al., 2011).

Figure 14: Land-Use intervention areas



Although a good mix of amenities is positive in many neighborhoods, the study specifically recommends a high land use mix in employment zones. Other than employment zones a few areas were identified in Mississauga where land use interventions can help discourage cars as primary mode share. The areas selected for increase in land use diversity are highlighted in figure 14.

4.3 Car Mode Share for Non-Work Trips

Similar to the work trip analyses presented in section 4.1, non-work trips considering traffic analysis zones as origin and destination are modeled and findings are summarized in this section:

Origin Model – Non-Work Trips

Analysis shows that the availability of high frequency bus services near home is a statistically significant predictor of low car mode share. Increase in density of high frequency bus stops by 1 bus stop per sq. km will decrease car mode share by 1.12 percent if all other variables are held constant. Land use diversity is also a significant determinant as land use diversity (Entropy Score) of 1 can decrease the car mode share by 0.07 percent. The impact of other variables on origin car mode share non-work trips, is provided in the table below.

Table 7: Origin Car Mode Share - Non-Work Trips

Variables	Coefficients	t Statistic	Lower Bound (95% CI)	Upper Bound (95% CI)
(Constant)	0.823**	5.273	0.515	1.131
Pop Density	-5.759**	-3.104	-9.418	-2.099
Entropy Score	-0.067**	-3.103	-0.110	-0.025
Transit Availability	0.162**	4.768	0.095	0.229
Bus Station Coverage	-0.065	-1.860	-0.134	0.004
HBFS Density	-1.124*	-2.446	-0.015	0.217
Vehicle Ownership	0.180	1.188	-0.119	0.479
HH Size	-0.031*	-2.080	-0.061	-0.002
Low Income	-0.327*	-2.187	-0.622	-0.032
* Significance at 95% interval			N - 195 Traffic Analysis Zones	
** Significance at 99% interval			R Square - 0.386	

Further, demographic characteristics are also associated with outbound car share for non-work trips. With increase in population density by 1000 people per sq. km, the car mode share is expected to decrease by 5.76 percent considering all other variables remain same. Further, results also show that TAZs with higher presence of low-income population tend to have less car mode share.

Destination Model – Non-Work Trips

For destination-non work trip model as well, the coverage of bus stop and GO station are statistically significant and negatively related to car use, revealing that proximity to bus and GO stations can decreases the car share of non-work trips by 0.07 and 0.03 percent respectively.

Further with increase in Walk Score by 10 points, transit mode share is expected to increase by 0.01 percent. While the average Walk Score in the Mississauga is 54, designated as “somewhat walkable“(Walk Score, 2019), Walk Score can be further improved through smaller interventions for pedestrians including but not limited to improvement in sidewalk designs, street furniture, landscaping, and pedestrian oriented signaling. Walk score can also be improved by diversifying the land use. Entropy Score is analyzed to assess the land use diversity, which shows a negative relation with car share. Hence, diversifying land use can directly and/or indirectly help reducing the non-work car share trips in Mississauga.

The results also indicate a high negative correlation of car mode share with population density. For destination non-work trips an increase in population density of 1,000 person per sq. km can decrease the car mode share by 6.66 percent. The impact of other variables, assessed in destination model, on car mode share non-work trips is provided in the table below

Table 8: Destination Car Mode Share - Non Work Trips

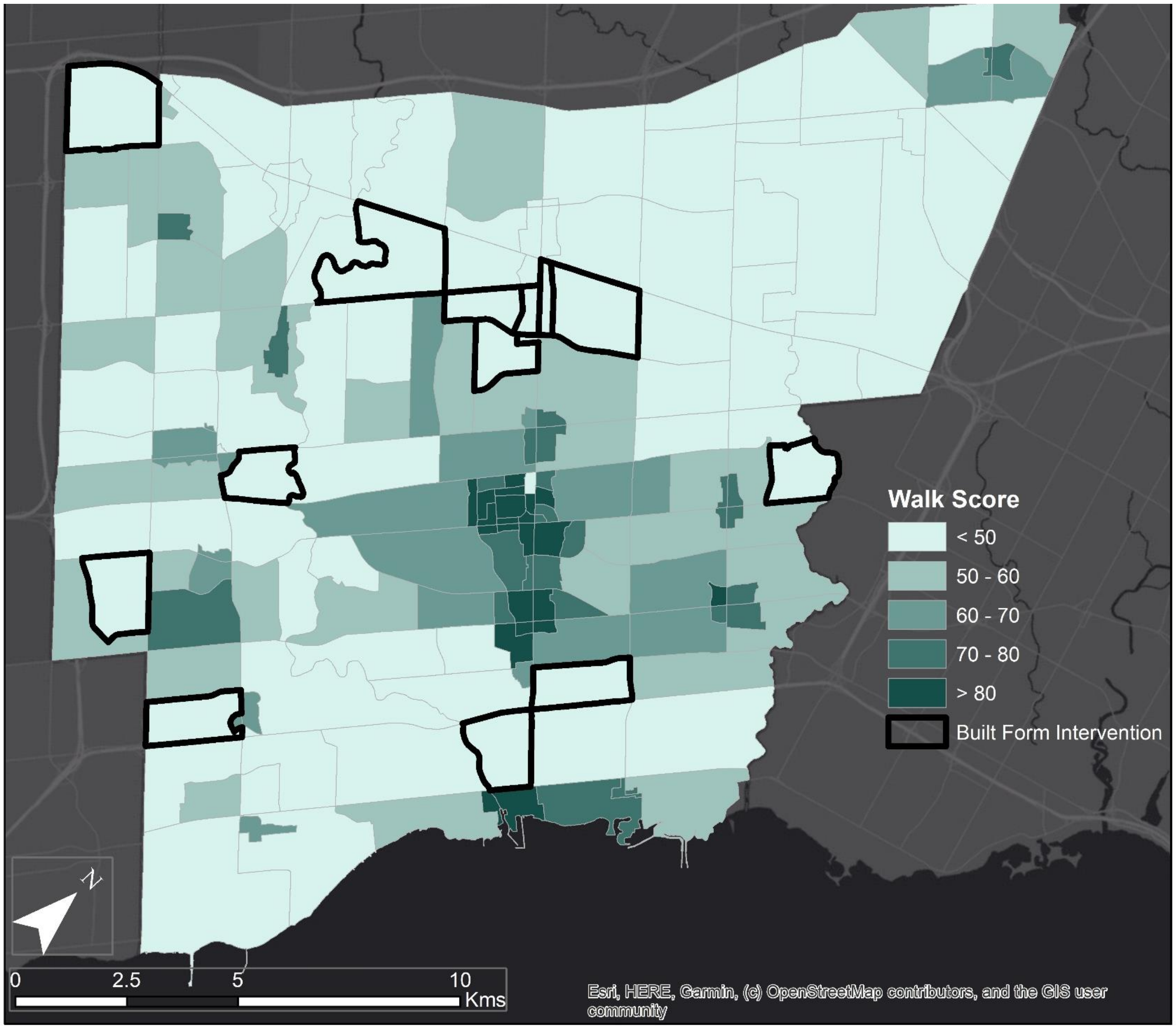
Variables	Coefficients	t Statistic	Lower Bound (95% CI)	Upper Bound (95% CI)
(Constant)	1.047**	15.731	0.915	1.178
Pop Density	-6.663**	-3.839	-10.087	-3.239
Entropy Score	-0.081**	-3.948	-0.121	-0.040
Walk Score	-0.001*	-2.287	-0.002	0.000
Bus Station Coverage	-0.073*	-2.140	-0.139	-0.006
GO Station Coverage	-0.034*	-2.015	-0.068	-0.001
Transit Availability	0.152**	4.856	0.090	0.214
HH Size	-0.015	-1.033	-0.044	0.014
Low Income	-0.492**	-3.872	-0.743	-0.241
* Significance at 95% interval			N - 195 Traffic Analysis Zones	
** Significance at 99% interval			R Square - 0.538	

4.4 Discussion of Findings – Non-Work Trips

The results of the above models for non-work trips indicate that the city needs to address the issues of walkability in most of the areas. Higher Walk Score values are generally associated with higher transit use, and proportionally lower car use. With a current average Walk Score of 54 (Walk Score, 2019), Mississauga needs to focus on improving its pedestrian infrastructure.

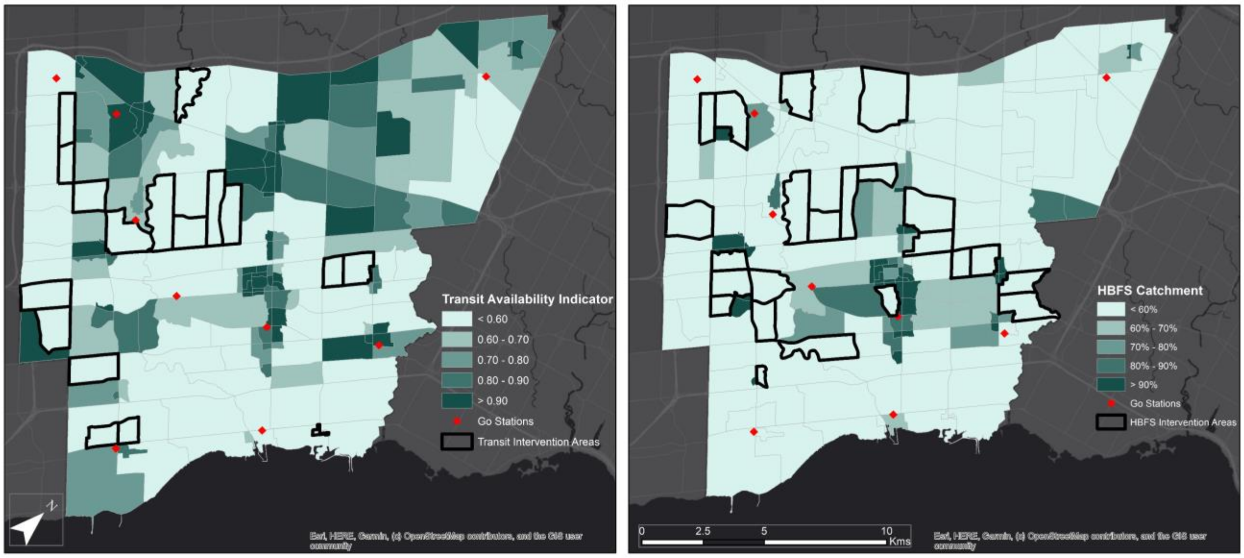
The highlighted traffic analysis zones in figure 16 indicate the areas with urgent need of improvement in walkability. These identified areas have a minimum population density of 1,000 people per sq. km and Walk Score of in a range of 40 to 50.

Figure 15: Improvement areas for walkability



Similar to work-trip model findings, analysis shows that the transit infrastructure is relevant to origin and destination non-work trips as well. The transit availability indicator is statistically significant in both the models. However, the significance of service coverage varies, while it is not statistically significant in the origin model, the service coverage it is statistically significant in the non-work trip destination model. Analysis also suggest that high frequency bus services catchment in the destination of non-work trips can encourage people to take transit as a mode choice. The areas identified for transit intervention are highlighted in the following figure.

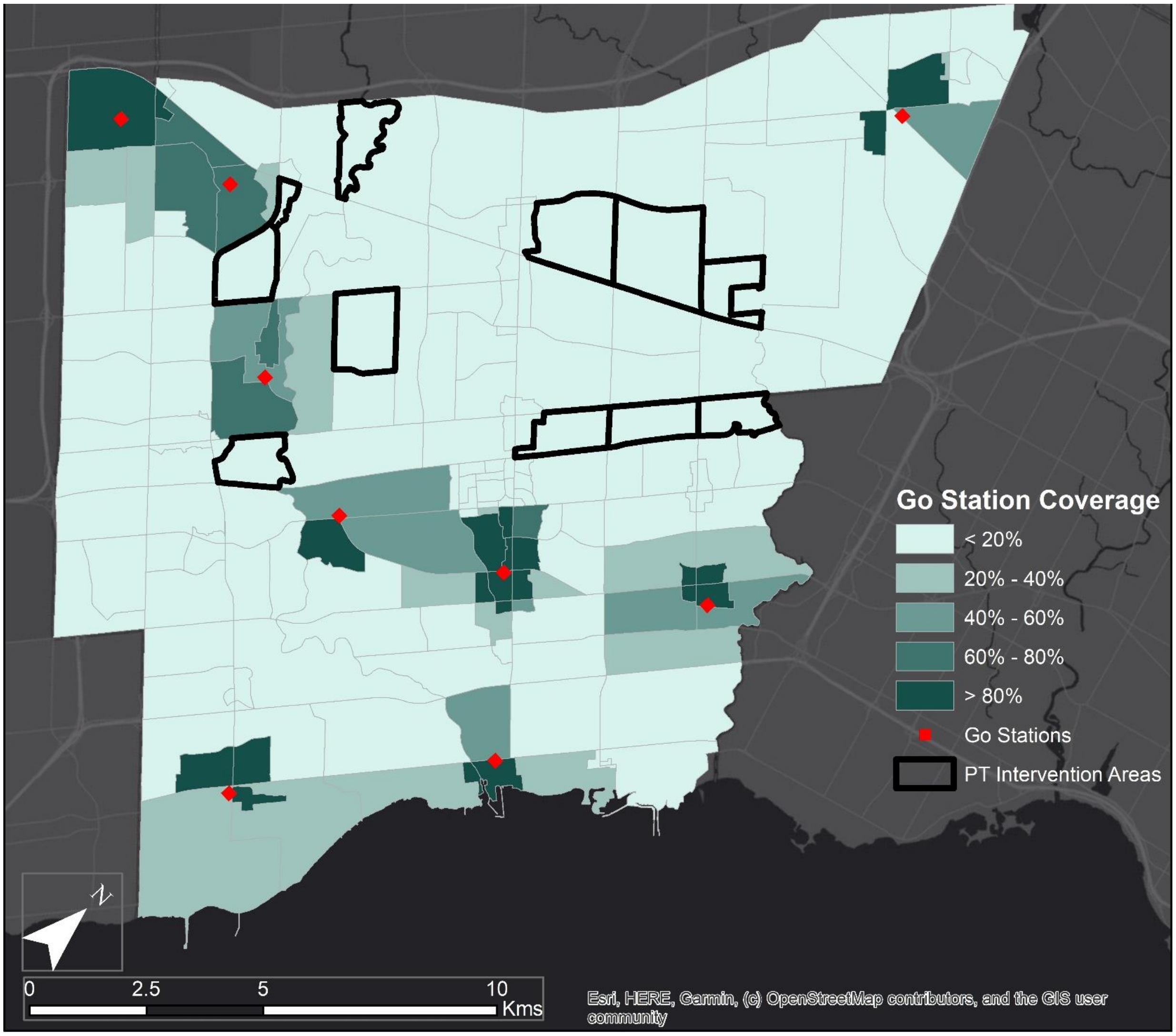
Figure 16: Areas identified for transit Intervention



GO station coverage was found statistically significant in origin model for work trips and destination model for non-work trips. Also, its negative relation with car mode share indicates that if provided with an increased catchment, the regional rail system can reduce the car dependency in Mississauga. A regional transportation system has a larger catchment area compared to bus or metro systems. Due to its vast catchment, GO stations generally work on park and ride models. Understandably, it is financially challenging to adjust or expand on the regional rail system. But it is possible to reduce the usage of cars by providing better bus connectivity to the catchment of the GO stations.

To increase the car mode share, it is proposed that high frequency bus services should be provided connecting GO station with the identified areas in figure 18. The identified intervention areas are selected having population density of more than 4000 people per sq. km or employment density of more than 2,000 jobs per sq. km. Additionally, these areas also fall outside one kilometre service area of GO stations and have a bus service catchment of less than 50 percent.

Figure 17: Areas identified for possible regional transit improvement



The areas highlighted in the figure-17 are selected for priority interventions. Changes in these areas can significantly reduce car share in the short term. However, for long term phased interventions, the City of Mississauga need to consider other areas which are falling behind on the assessed parameters in this study.

Some of the built environment research indicate that people who choose to live near transit stations are more likely to use public transit Cervero (1994). One of the ways to encourage the use of modes of transportation other than the private vehicle is to increase the housing and employment opportunities near public transit stations. Built environment including physical spaces, buildings, land-use, and infrastructure influence an individual's travel behavior (Brownson et al. 2009, Ewing and Cervero, 2001; Ewing and Cervero, 2010).

5 Conclusion

This study tests variables of built environment, socio-economy, and transit services to predict the car mode share of Mississauga. To do so, a series of multiple linear regression analysis for origin and destination trips associated with work and non-work purpose is performed. The results confirm the importance of built environment and transit service variables in changing the car mode share in Mississauga.

First level of analysis found population density and land-use as important variables, influencing car mode share in the city. It was also found that Mississauga stands very low on walkability parameter of Walk Score. Statistically significant in only one of the models, Walk Score is a proxy to multiple variables including land use diversity, transit availability, and active transport infrastructure etc. In addition, multiple transit services variables are also found crucial to the car mode share. Bus station coverage, GO station coverage, and high frequency bus stop density are identified to have a negative relation with Car share in all traffic analysis zones in Mississauga.

5.1 Recommendations

The following recommendations reflect the needs to the identified the priority zones, however, these recommendations can also be applicable to other TAZs facing similar issues:

Increase densities and diversify land-use around identified areas and transit stations

Study found the population density and land-use as one of the key variables negatively related to the car mode share in all the models except the destination model for work trips. Which means density and land-use modifications are required to increase the population density in Mississauga, especially in identified priority areas highlighted in figure – 13 and 14. Further, Mississauga also needs to focus on diversifying the land use as the results indicate that those areas falling behind on entropy score have a higher car share.

Maximize land use potential within transit catchments

Literature shows that riders typically walk up to 1,000 meters to access high-capacity transit and about 400 meters to access bus services. It is recommended that Mississauga shall perform a study to identify the preferences of local population for first and last mile trip. Also, zoning designations with compact developments should be planned to allow transit-supportive densities in the transit catchments. As the convenience of proximity to the transit helps encourage transit usage for both work and non-work trips.

Promote Employment Growth along GO transit corridors

The study found that the catchment of southern GO transit line has both low population and employment density. It is therefore proposed that the catchment area of the southern GO corridor to be strategically zoned to accommodate better employment and/or population densities. The proximity to transit services and GO station catchment was found to be a strong predictor of car share as greater accessibility to transit services will incentivize people to use transit over car.

Improve built environment

It is well established in the literature that built environment supporting walking and cycling plays a major role in promoting transit as a mode choice. Improved built environment not only provides convenience in the first and last miles but also reduces car usage for short distance trips. As Mississauga currently stands low on walkability score, it is proposed that the city needs to improve its active transport infrastructure in the areas identified in the figure -15. In addition, the city shall carry out planning studies to identify the current gaps in active transportation infrastructure.

5.2 Study Limitations and future research

The findings presented in this study are intended to help Mississauga to reduce its current car mode share. Future studies could use a similar methodology to evaluate changes in mode share before and after interventions to determine the accuracy of such models. Additionally, the study uses a cross sectional analysis to identify the factors influencing mode share, similarly a temporal analysis of variables can be undertaken to see how car mode share has changed overtime against different variables. Furthermore, this study did not consider dummy variables, which can be incorporated in future studies to proxy presence of transit facilities and other services.

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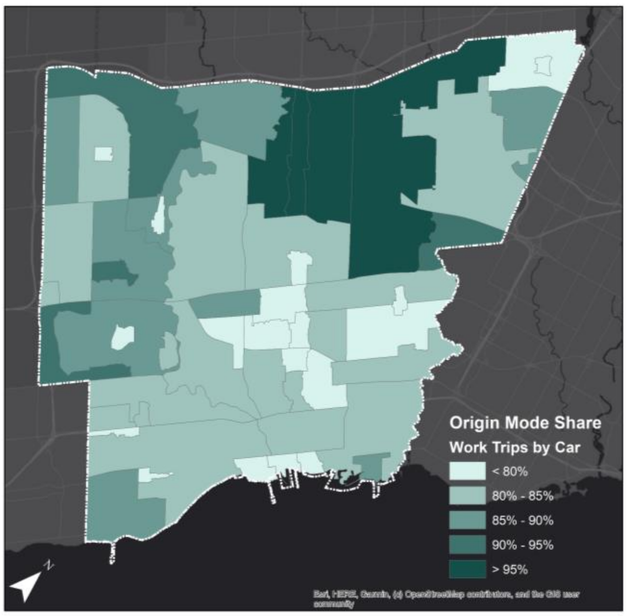
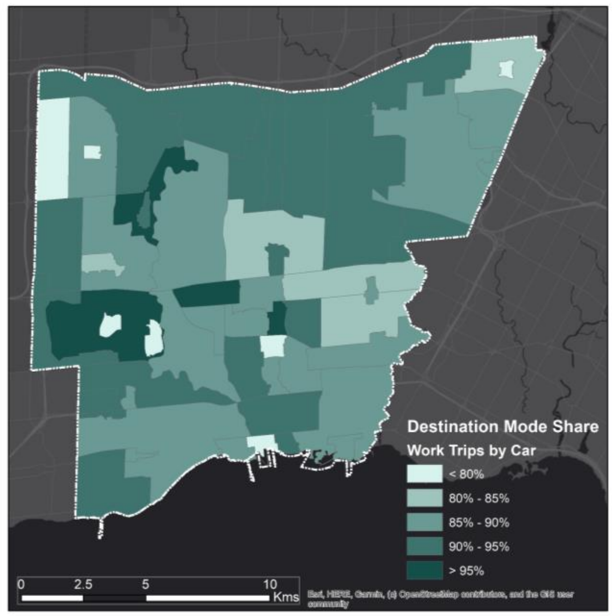
Appendix A: Character Area Level Analysis

Mode Share – Work Trips

Character Areas as Origin

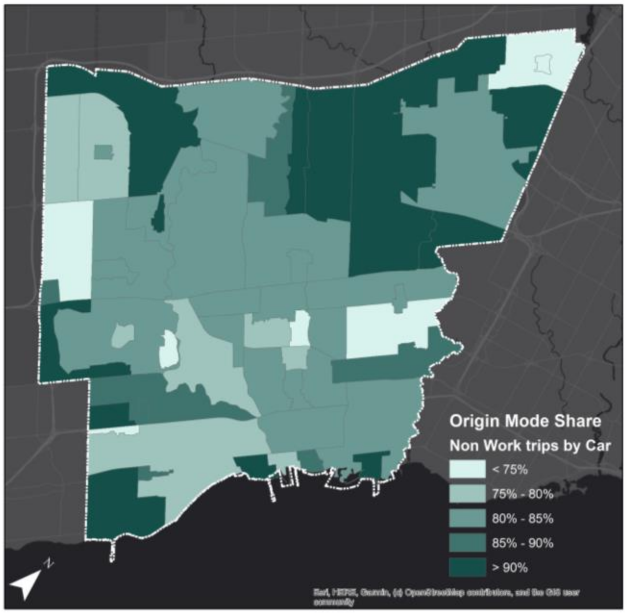


Character Areas as Destination

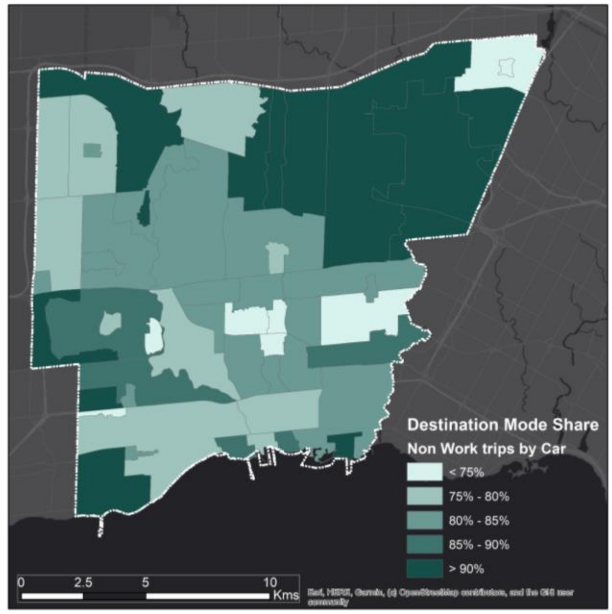


Mode Share – Non Work Trips

Character Areas as Origin



Character Areas as Destination



Regression Results
Car Mode Share – Work Trips

Origin Car Mode Share – Work Purposes

Variable	Coefficient	T-Statistic	Lower Bound (95% CI)	Upper Bound (95%CI)
(Constant)	0.828**	10.351	0.667	0.989
Population Density	-1.664**	-4.266	-2.449	-0.878
Accessibility (Car)	1.316*	3.276	0.507	2.125
Go Coverage	-0.096**	-3.702	-0.148	-0.044
High Frequency Bus Stops	-0.003**	-3.941	-0.004	-0.001
Entropy Score	-0.038	-1.047	-0.110	0.035
Street Density	0.004	1.031	-0.003	0.011
Unemployment	2.071*	2.013	-0.002	4.143
Low Education	-1.759*	-4.293	-2.584	-0.934
Vehicle per HH	-0.044**	-2.564	-0.078	-0.009

* Significance at 95% interval N - 56 Character Areas
** Signigicance at 99% interval R Square - 0.78

Destination Car Mode Share – Work Purposes

Variable	Coefficient	T-Statistic	Lower Bound (95% CI)	Upper Bound (95%CI)
(Constant)	0.857*	8.766	0.660	1.053
Population Density	-0.181	-0.381	-1.141	0.778
Accessibility (Car)	0.414	0.844	-0.574	1.403
Go Coverage	0.008	0.267	-0.055	0.072
High Frequency Bus Stops	-0.003*	-4.099	-0.005	-0.002
Entropy Score	-0.013	-0.292	-0.101	0.076
Street Density	0.004	0.859	-0.005	0.012
Unemployment	2.912**	2.317	0.380	5.443
Low Education	-1.414*	-2.825	-2.422	-0.406
Vehicle per HH	-0.040	-1.929	-0.082	0.002

* Significance at 95% interval N - 56 Character Areas
** Signigicance at 99% interval R Square - 0.41

Regression Results
Car Mode Share – Non Work Trips

Origin Car Mode Share – Non Work Purposes

Variable	Coefficient	T-Statistic	Lower Bound (95% CI)	Upper Bound (95%CI)
(Constant)	0.8356**	8.3420	0.6338	1.0373
Population Density	-1.6087*	-3.2947	-2.5921	-0.6253
Accessibility (Car)	0.3731	0.7418	-0.6399	1.3861
Go Coverage	0.0182	0.5600	-0.0473	0.0837
High Frequency Bus Stops	-0.0011	-1.3043	-0.0027	0.0006
Entropy Score	0.0886*	1.9696	-0.0020	0.1793
Street Density	-0.0002	-0.0471	-0.0091	0.0087
Unemployment	2.4623	1.9113	-0.1325	5.0570
Low Education	-1.2936*	-2.5213	-2.3269	-0.2602
Vehicle per HH	-0.0657**	-3.0885	-0.1085	-0.0228

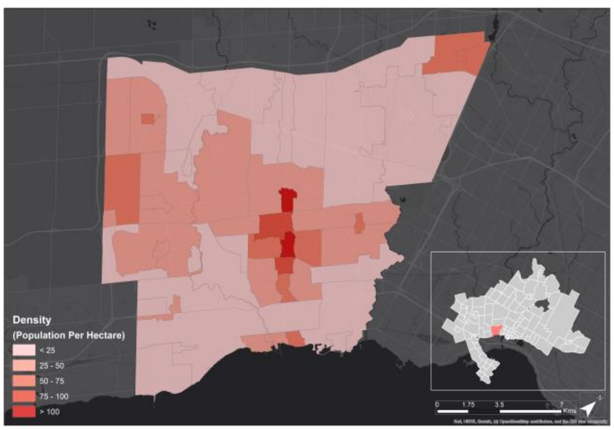
* Significance at 95% interval   N - 56 Character Areas
** Signigicance at 99% interval   R Square - 0.50

Destination Car Mode Share – Non Work Purposes

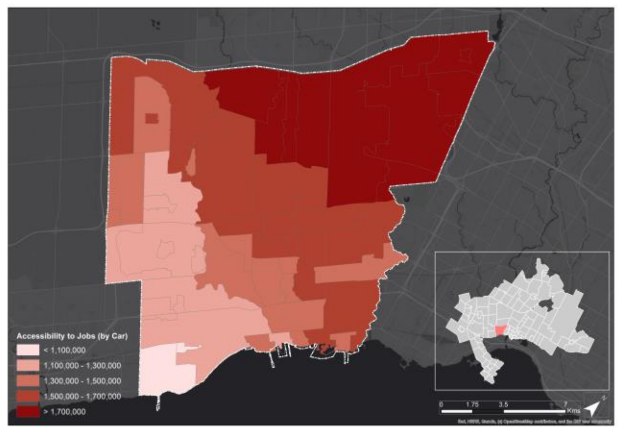
Variable	Coefficient	T-Statistic	Lower Bound (95% CI)	Upper Bound (95%CI)
(Constant)	0.8692**	9.3645	0.6822	1.0561
Population Density	-1.8089**	-3.9980	-2.7201	-0.8976
Accessibility (Car)	0.5930*	1.2725	-0.3456	1.5317
Go Coverage	-0.0128	-0.4264	-0.0735	0.0478
High Frequency Bus Stops	-0.0019*	-2.4777	-0.0034	-0.0004
Entropy Score	0.0757	1.8151	-0.0083	0.1597
Street Density	0.0018	0.4351	-0.0065	0.0100
Unemployment	2.3170	1.9410	-0.0873	4.7214
Low Education	-1.3951*	-2.9346	-2.3526	-0.4376
Vehicle per HH	-0.0869**	-4.4109	-0.1266	-0.0472

* Significance at 95% interval   N - 56 Character Areas
** Signigicance at 99% interval   R Square - 0.65

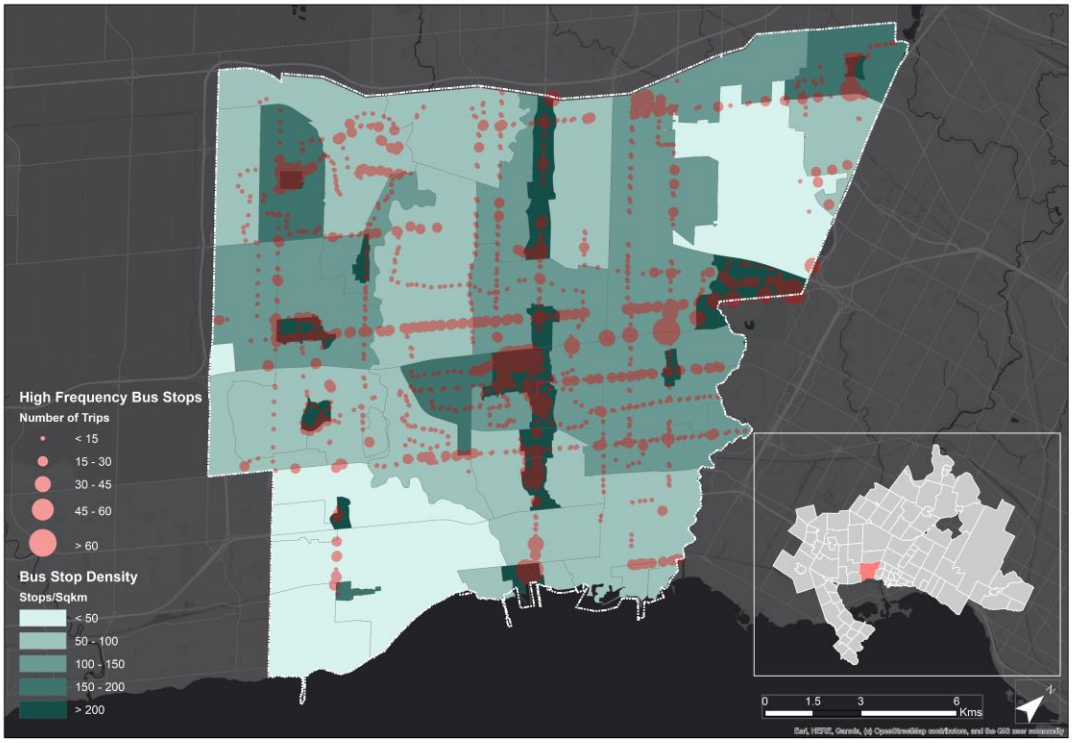
Population Density of Mississauga



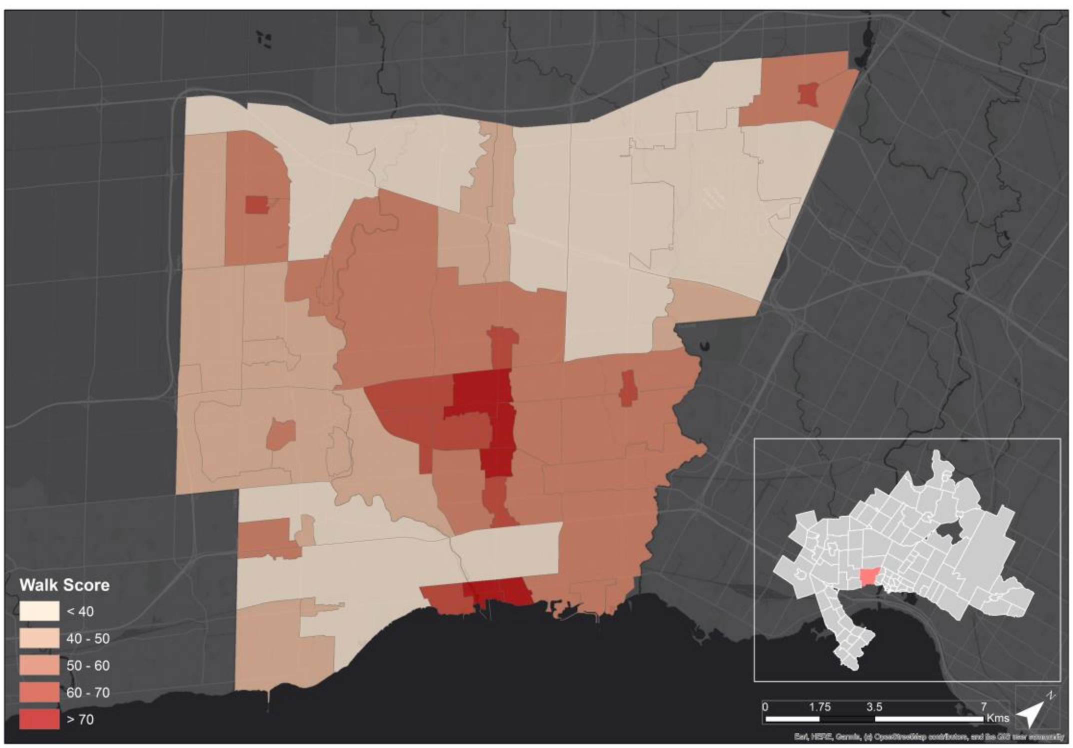
Accessibility to Jobs by Car under 60 mins



High Frequency Bus Services in the Area



Walk Score©

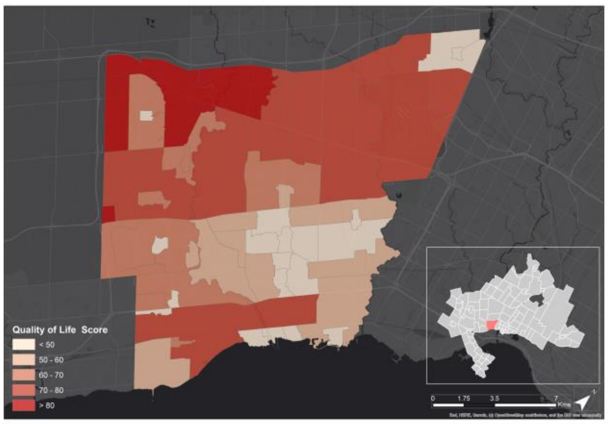


Land Use Diversity

Entropy Score

Simpson's Index

Neighbourhood Index (Region of Peel)



Proximity Index (Statistics Canada)