AN ANALYSIS OF FACTORS AFFECTING COMMUTING DISTANCE IN GTHA

AN ANALYSIS OF COMMUTING DISTANCE AND ITS CONTROLLING FACTORS IN THE GREATER TORONTO-HAMILTON AREA

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ABSTRACT

The increasing length of the daily commute is a major issue for many commuters in the Greater Toronto and Hamilton Area (GTHA). In order to alleviate this problem through policy, the policy makers require more in-depth understanding of this issue. This study explores different travel behaviour, socioeconomic and labour market determinants of commuting distance for resident workers in the GTHA, especially those having normal commutes and those having extreme commutes. This study also explores which areas of the GTHA are most self-contained, and what are the average commuting distances of each sub-region of the GTHA. The primary data source for this study was Transportation Tomorrow Survey (TTS) for the year 2011. Supplementary data were obtained from InfoCanada and Statistics Canada.

Descriptive analysis in this study, focused at the Census Sub-Division (CSD), examined self-containment, outbound commutes, inbound commutes, resident employees and jobs densities, and average commute distances for place of residence and place of work. Study results showed that Toronto and Hamilton CSDs are the most self-contained areas in the GTHA, whereas areas located in the north and northwest of Toronto are major sources of outgoing commutes. Toronto and its adjacent CSDs have the lowest average commuting distance, whereas residents of Georgina and Brock commute exceptionally long distances.

Multivariate regression analyses were applied to a disaggregate dataset (TTS). Workers older than 15 years of age living in the GTHA were divided into two major categories based on the length of their commute: (i) normal commuters (those having a mean commuting distance of 10.8 km) and (ii) extreme commuters (those having a mean commuting distance of 40.9 km). Factors affecting commuting distance for these two groups were examined. Similarly, residents living and working in the GTHA were divided into two categories: Resident workers living in (i) Jobs-rich areas or (ii) Resident-rich areas. Factors affecting commuting distance of these resident workers were also examined. The key controlling factors of commuting distance include gender, age, mode of transportation, employment status, ratio of jobs to employed residents, age of youngest child, auto availability in household, multi-worker household, median income, jobs and population density, and distance from CBD. Significant socioeconomic, travel behaviour and land use determinants for normal commute distances were also applicable to extreme commute distance. Transit was the preferred mode of transportation for long distance commuters in the GTHA, except for those living in job-rich areas. Workers associated with Sales and Service occupation and living in jobs-rich areas exhibited shorter commute than those in General/Clerical occupation. These findings are important to understand the changing travel patterns and behaviours of commuters in the GTHA. These results will be of interest to transportation planners, engineers, and policy makers as it highlights the inclination of long distance commuters to use transit.

Keywords: Commuting Distance, Extreme Commuters, Jobs-housing balance, Self-Containment, Urban Planning.

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ABBREVIATIONS AND SYMBOLS

CMA – Census Metropolitan Area

CBD – Central Business District

CSD – Census Sub-Division

GTHA – Greater Toronto and Hamilton Area

TAZ – Traffic Analysis Zone

DA – Dissemination Area

JER – Ratio of Jobs to Employed Residents

TTS – Transportation Tomorrow Survey

VKT – Vehicle Kilometers Traveled

Symbols in results of Multivariate Regression:

‘ ’ Significance level >= 0.1 -------- (More than 10% chance of Type 1 error, i.e. rejecting the Null Hypothesis as false when it is true)

. Significance level <= 0.1 -------- (10% chance of Type 1 error)

* Significance level <= 0.05------- (5% chance of Type 1 error)

** Significance level <= 0.01------- (1% chance of Type 1 error)

*** Significance level <= 0.001 ----- (0.1% chance of Type 1 error)

1. INTRODUCTION

1.1. History of Changing Commuting Patterns and Context

Since the start of the 20th century, urban areas in North America have experienced shifts in population from city cores to their suburbs. Traditionally, suburbs started to emerge as residential areas with people commuting to city centres for work and other activities. As a result, cities started to become more sprawled and commuting patterns changed. Studies conducted by Taylor (1915) and Douglas (1925) made an early contribution in the urban sociology literature, showing the distinction between two main types of suburbs: employment and residential. Later, Schnore (1963) recognized an intermediate type of suburb; having both residential and employment areas. He suggested that the characteristics of the intermediate class of suburbs tend to fall somewhere between those of employment and residential. Over time, the movement of people away from the urban core to outskirts of cities has been divided into three waves of suburbanization. The first wave involves the steady flow of residents from urban areas to suburbs, while the second wave involves migration of retail activities, typically including massive indoor shopping malls in the 1950s and 1960s (Cervero, 1989). In the 1980s, urban planners and researchers witnessed America's third wave of suburbanization involving the mass movement of jobs to the suburbs (Orski 1986; Leinberger & Lockwood, 1986). Business parks, office towers, white-collar office jobs and service jobs highlighted this third wave. With the decentralization of population and employment, and the suburbs converting from origins of commuting trips to both origins and destinations, another trend emerged – the increasing use of automobiles. These trends changed the face of North America's suburbs. The suburbs were not just the origins of commuting trips; they were also major destinations (Cervero, 1989). All these changes have shaped the urban landscapes in North America in such a way that cities have become polycentric rather than monocentric

(Maoh & Kanaroglou, 2007; Maoh & Tang, 2012). What used to be a daily commute to and from the city centre was no longer the case.

It was expected that commuting times and distances would shorten because more jobs were locating in suburbs and new central business districts (CBD) were emerging as well. However, this has not been the case in reality. Commuting distances have steadily increased over time. In Canada, the median commute distance has increased from 7 km in 1996 to 7.6 km in 2006, while the average round trip commute time has increased from 54 minutes in 1992 to 63 minutes in 2005 (Statistics Canada, 2006; 2007).

Overall the relationships between urban form, residential location, and commuting are not well understood in Canadian urban areas (Axisa et al., 2012). Many researchers have analyzed the reasons behind the continued lengthening of commuting distances in North American cities (Cervero, 1989; Maoh & Kanaroglou, 2007; Axisa et al., 2012; Maoh & Tang, 2012; Newbold et al., 2015). They have attributed the increase in commuting distances to a variety of socioeconomic, labour market, land use, travel behaviour and household factors.

In recent years, the focus of many studies has been on jobs-housing balance and self-containment of an area (Cervero, 1989; Yigitcanlar et al., 2007). Planners, environmentalists, academics and policy-makers have been voicing their concerns about the geographical distribution and balance of jobs and housing in large metropolitan areas to curb the lengthening commutes. This has been a controversial debate. Many researchers argued that by attaining an optimum jobs-housing balance in an area, the commuting distances would shorten, resulting in efficient travel time between work and home. Many researchers disagree, arguing that jobs-housing balance is attained over time due to market forces, but achieving a good balance does not immediately lead towards a self-contained area. The supporters and proponents of decentralization of urban cores often cite the co-location theory (Levinson & Kumar, 1994). According to this theory, workers tend to avoid the travel-time cost by periodically changing their workplace or residence, while employers also change their firm locations in a free-market system, following locations of customers and workers. Thus a jobs-housing balance emerges over time, reflecting the mutual adjustment between housing and jobs. It results in reduced commuting time and less traffic flows. Therefore, as per this theory, the commuting times would not change or they would remain relatively stable over time (Levinson & Kumar, 1994).

The Greater Toronto-Hamilton Area (GTHA) in southern Ontario, Canada is the largest metropolitan area in Canada. It is also among the large urban centres of North America. The population of this area was 6,574,140 as of 2011 (Statistics Canada, 2011). It experienced a large population growth (8.4%) between 2001 and 2006. Between 2006 and 2011, the population growth was 5.7% (Statistics Canada, 2007; 2011). As of 2011, 49.6% of the provincial population lived in the GTHA. The GTHA attracts a large number of workers having different skills, education and income levels. One major reason behind the rapid increase of population in the GTHA is in the attraction of immigrants that find this region desirable due to its versatility, ethnic mix, and job opportunities. With increasing population and limited availability of housing, the demand for affordable housing has increased rapidly, giving rise to suburbs that have now shaped GTHA as a polycentric region (Maoh & Kanaroglou, 2007). The movement of people to suburbs results in the reduction of congestion in city cores, but long commuting distances result in extreme congestion on highways during peak travel hours. On the other hand, increased use of single-occupant vehicles has been associated with high energy consumption and air pollution (Scott et al., 1997; Behan et al., 2008). The surge in vehicle ownership, increase in commuting distances, increased congestion on highways and increase in travel time to and from these suburbs have a large impact on commuting patterns in the region, with serious economic, social and environmental implications. These impacts become worse with increases in population and expansion of suburbs in the GTHA.

In this study, factors affecting the commuting distance have been explored using the latest available (2011) data at the time of this study in order to understand how the recent trends of population growth and suburban living are shaping the self-containment and commuting patterns in the GTHA. A literature review has also been conducted about increasing commuting distances in large urban areas and the debate among various researchers on topics like self-containment and jobs-housing balance.

1.2. Thesis Outline

The remainder of this thesis is formulated as follows:

Chapter 1 describes the study objectives, significance, and an overview of the methodologies used in this thesis.

Chapter 2 provides a descriptive analysis of commuting patterns in the municipalities or Census Sub-Divisions (CSDs) of the GTHA. It also examines the methods used by researchers to measure self-containment and average commuting distances observed in GTHA municipalities. For this analysis the CSD-level aggregate dataset have been used.

Chapter 3 deals with statistical data analysis to identify the factors that affect home-to-work commuting distance for employed residents of GTHA. For this analysis, disaggregate data have been used so that the determinants of commuting distance can be calculated more accurately for employed persons. This disaggregated approach enabled the division of the dataset into normal and extreme commuters for further analysis of determinants of their commuting distances. Five models have been analysed using multivariate regression technique. In the first model, the determinants of commuting distance have been analysed for the entire study area. Following that, residual analysis was performed and the main dataset was divided into two major subsets for analysing determinants of commuting distance for normal and extreme commuters. The last two models analysed commuting distance determinants for commuters residing in either jobs-rich or resident-rich areas.

In summary, the analysis conducted in Chapter 2 provides information about population dynamics, outbound and inbound commute, travel self-containment and average commuting distances of GTHA municipalities addressing study objectives 1 & 2. The analysis conducted in Chapter 3 provides information about major factors affecting the commuting distance of workers for the entire study area which addresses study objective 3. Chapters 2 and 3 have been written as independent chapters, therefore there is some overlap in study area and data descriptions.

Chapter 4 provides discussion and concluding comments.

1.3. Study Objectives

The main objectives of this study are to explore commuting patterns and distances of workers in the Greater Toronto-Hamilton Area (GTHA). In addition, this study explored how self-contained are the various regions (Census Sub-Divisions) of the GTHA. Average commuting distances have been analysed for both place of work and place of residence. Factors that affect commuting distance have been analysed using the disaggregate dataset to understand which controls or indicators are most crucial in contributing towards lengthening commutes in the region.

Specific objectives are:

(1) To determine how self-contained are the various communities in the GTHA and how their residents and workers commute.

(2) To explore the differences in commuting patterns in these communities and analyse travel pattern information.

(3) To determine the travel behaviour, socioeconomic and labour market factors affecting the commuting distance of workers in the GTHA, and whether or not a balanced ratio of jobs to employed residents contributes towards curbing the commute distance.

The answers to these questions will offer further insight on the relationship between transportation and land use in large contiguous urban areas like GTHA. The segmentation of data into normal and extreme commuters is an almost unique approach and has been employed in one recent study by Maoh and Tang (2012). Also, comparison between the determinants of commute distance for commuters from resident-rich and jobs-rich areas will improve the knowledge on commuting behavior and its relation to urban form.

1.4. Methodologies and Variables Used

In order to address the study objectives listed in Section 1.3, analyses have been conducted at both aggregated and disaggregated levels. The first two study objectives are addressed in Chapter 2, while the third study objective is addressed in Chapter 3.

Using the aggregated data of Census Sub-Divisions, descriptive analysis has been conducted in Chapter 2 in order to provide an overview and background of commuting flows in GTHA. Statistics related to population, jobs, resident employees, outbound and inbound commute, and average commuting distances of these CSDs have been studied. This descriptive analysis helps in highlighting the population dynamics and traffic flow patterns for resident workers in GTHA. This analysis also sheds light on self-containment and average commuting distances of CSDs, which is essential to put things in perspective for more detailed analyses on determinants of commuting distance conducted in Chapter 3.

The statistical method used in Chapter 3 is Multiple Linear Regression (MLR) that has been utilised for determination of factors affecting commuting distance in a region. MLR uses several explanatory variables (also known as predictors or independent variables) to predict the outcome of a response variable (also known as dependent variable). The goal of MLR is to model the relationship between the predictors and response variables. For example, predictors like the mode of transportation, age, median income, and presence of children in household, can all have an effect on the commuting distance of an individual living in GTHA. MLR can be used to model the impact that each of these predictor variables has on the commuting distance. MLR also measures the direction and strength of the functional relationships, linking the predictor variables to the response variable and the remaining error is analysed. The results from this technique also provide useful information on absolute and relative ability of each predictor variable to explain the response variable while holding the effect of other predictor variables constant.

The dependent variable is the log of commuting distance of one way work-trips (from home to work), for workers over the age of 15, and the unit of analysis is *employed persons* in the GTHA region.

Commuting distance has been analyzed as a function of various explanatory variables related to socioeconomic, demographic, labour market, travel behaviour and household characteristics of resident workers of GTHA. Among the explanatory variables, jobs-housing balance in a region was analysed by using the information on resident workers and number of jobs in a particular area. The simplest and most frequently used measure is the ratio of jobs to employed residents (JER) for a geographical area (Cervero, 1996; Yang 2005; Yang & Ferreira, 2009). Other explanatory variables include gender, age of respondent, employment status, student status, primary mode of travel, possession of transit pass, possession of driver's license, auto ownership, type of household, age of youngest child, median income, occupation type, distance from CBD, jobs density in place of employment and population density at the place of residence.

1.5. Study Significance

- This research work will help in understanding the dynamics surrounding population, jobs, outbound and inbound commute, travel self-containment and average commuting distances in the GTHA. It will also help to identify the sub-regions that are sending or attracting commuters, and making the specific policies for these sub-regions.
- This research will also help to determine major factors that are contributing towards lengthening commuting distances of workers from these communities using the latest dataset, although on a disaggregate level.
- This analysis was conducted using the most recent traffic and census datasets at the time of study from InfoCanada (2011), Statistics Canada (2011) and Transportation Tomorrow Survey (2011). Therefore, it helps to determine how commuting patterns and commuting distances have changed in recent years in the region. It can help to evaluate the effectiveness and deficiencies of past efforts to improve transportation programs in the region. This knowledge will also help policy makers in Ontario and Canada to develop new transportation policies and transportation facilities and networks.
- The insights from this analysis will also help in future urban planning by understanding the determinants of commute distance using the latest dataset, and understanding whether the whole region is heading for being a compact region or a sprawled one.
- Insights from this analysis can be helpful for the municipalities, provincial government and private transportation agencies in decision-making of potential future investments in accessible and sustainable regional mobility. For example, this analysis could help Metrolinx, the regional transportation authority for the GTHA, to improve and further expand their regional transit services. It can also help them to improve accessible cross boundary travel in the GTHA by

coordinating with municipalities which is one of their main objectives under 2015 – 2020 Metrolinx Five Year Strategy (Metrolinx, 2014).

2. DESCRIPTIVE ANALYSIS OF COMMUTING DISTANCE AND SELF-CONTAINMENT FOR CENSUS-SUB DIVISIONS IN THE GTHA

2.1. Background and Literature Review

2.1.1. Self-containment of an Area

According to Burby and Weiss (1976), self-containment relates to achieving a built form that allows people to live, work, shop and recreate within a defined geographical area or community. Thomas (1969) defines this concept as a place where most needs of people for everyday living, including work and shops and other services are provided. Margolis (1957) described that “balanced” communities are where the ratio of jobs to housing units lies within the range of 0.75 to 1.25. Ebenezer Howard (1898), who is considered one of the city-planning pioneers, also worked towards achieving self-containment when he presented the ‘Garden City’ concept. He suggested ‘Garden Cities’ should be planned in such a way that they are socially and economically self-sustaining communities. Howard (1902) suggested that the ‘Garden City’ is aimed to physically contain all the necessary aspects of community life, including employment, but with strong connections to a greater metropolitan region. With the New Towns movement in the United States and Europe, the idea of complete communities was revived (Burby & Weiss, 1976). Later it was also adopted by many other countries (Lee & Ahn, 2005).

However, over time, these Garden Cities and New Towns failed to be self-contained with regards to commuting trips (Cervero, 1995a; 1998). According to Cervero (1989), the ratio of jobs to employed residents indicates only the potential for balance. The degree to which that potential was realized was reflected by the share of the jobs in a community that are actually filled by their residents and conversely by the share of workers finding a residence in that community (Cervero 1989).

2.1.2. Methods used for Measurement of Self-containment

Various methods were utilized to measure the self-containment of an area by different researchers and government bodies. Statistics Canada describes self-containment as the measurement of the degree to which the workers living in an area are also working in the same area. Upon crossing a certain threshold for self-containment, the area is considered a self-contained labour market. This is because most residents with jobs are working in the given labour area and most individuals living in the given labour area are also working in the given labour market area. This threshold is defined through a sliding scale that requires a high degree of self-containment if the area has a small resident labour force. For a Census sub-Division (CSD[1]) with less than 1,000 resident workers, the minimum self-containment level is set at 90%. For larger CSDs (with over 25,000 resident workers), the self-containment level is set at 75%. This is the lowest benchmark for measuring self-containment by Statistics Canada. (Statistics Canada, 2014).

Statistics Canada defines self-containment as a combination of two components:

1. Self-containment of workers that measures the percent of workers in the area that also live in that area.
2. Self-containment of residents that measures the percent of residents in an area that also work in the same area.

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[1] Census Subdivisions (CSDs) are the root geographical aggregation of both Large Urban Center (LUCs) and Rural and Small Town (RST) areas. CSDs are simply municipalities (determined by provincial legislation) or their equivalent (i.e., Indian reserves or settlements and unorganized territories). Geographically, CSDs can range from the vast areas of the unorganized territories found in the northern reaches of many provinces to less than one square kilometer for a small rural town. CSDs can also range in population size from 2 million plus, to only a few residents in more remote regions (Harris Alasia, & Bollman, 2008)

Thomas (1969) described that all British New Towns were designed to be balanced as well as self-contained. Thomas created an "Independence Index" in order to track changes in self-containment in these towns from 1951 to 1966. This Independence Index referred to the number of internal (within community) work trips divided by the sum of in and out (external) work trips. The higher the value, the more "independent" or self-contained the community. Thomas found that early British New Towns became more self-contained over the course of the 1960s.

In the US, Cervero (1989) found a number of San Francisco Bay Area suburban communities that were quantitatively balanced but not self-contained in terms of commuting. There was less than one in four jobholders working in town, while around 85 percent of workers were imported from the outside.

Cervero (1989) considered the following parameters in his study.

(1) Number of residents in the community who are employed.
(2) Number of workers in the community.
(3) Number of workers in the community who reside locally.
(4) Ratio of jobs to housing, approximated by ratio of workforce to employed residents, (2)/(1).
(5) Percent of workers who reside locally, (3)/(2).
(6) Percent of employed residents who work locally, (3)/(1).

He presented two empirical analyses for the US New Towns using two methods. The first method was for group comparisons that used analysis of variance (ANOVA) F-statistics to test whether differences in commuting characteristics are statistically significant across three classes of New Towns (i.e. residential, employment and balanced communities). The second method was matched-paired comparisons, using *t* statistics, to estimate whether differences in commuting between planned and less planned communities are significant. Mainly the ANOVA tests were used to examine whether commuting varies by levels of jobs-housing balance; whereas the matched-pair comparisons examined the influence of master-planning on commuting. Important variables used in his study were population density (person/sq.km), median household income, median household rent, median home value, housing density (houses/sq.km), jobs-worker ratios, job-housing ratio, mean commute times in minutes and distance from regional CBD.

Self-containment of New Towns is of interest to researchers as is the self-containment of existing large urban areas. Planned communities in more remote locations, such as many second-generation New Towns in England, can be expected to have relatively high rates of automobile travel in part because of the tenancy of less transit services available and low traffic congestion (Cervero, 1995a). Cervero (1995a) compared new towns in the US, the UK, France and Sweden to investigate the relationship between commuting and self-containment. He found that new towns in the US and the UK are highly balanced as well as highly self-contained. However, automobile dependency in these towns was fairly high too. In contrast, the new towns in France and Sweden were found to be less self-contained but, side by side, highly dependent on public transit. Thus, he concluded that the availability of a public transit service has a very strong influence on the choice to commute for employment purposes. He further argued in another study (Cervero, 1995b) that the new towns of Stockholm (Sweden) are sustainable not because of balanced growth or self-containment but, rather, because of the strong rail-services in these towns. Thus the sustainability of these new towns lies at the strength of its transport system and residents’ accessibility to public transit.

While studying the self-containment and commuting patterns of new-town residents in Hong Kong, Hui and Lam (2005) and Lau (2010) argued that new-town development has contributed to population dispersion from old urban areas to suburbs. These new towns failed to achieve self-containment, and that has resulted in widespread cross district commuting between new towns and old urban areas. This type of pattern has resulted in longer travel times and longer commuting distances in these areas.

Lee and Ahn (2005) measured the levels of self-containment of Seoul's (South Korea) new towns by investigating patterns of non-work-related trips. They noted that shopping centers in these towns attract a significant number of non-residents from surrounding areas. Although these new-town residents are highly dependent on the central city in terms of commuting trips, however, in terms of non-work-related trips, these towns play the role of suburban centers.

The location of New Towns is an equally significant factor. Jun and Hur (2001) estimated the commuting costs associated with Seoul's new-town development. However, their study was under the assumption of contiguous new-town development for locations within Seoul's Greenbelt. The authors concluded that if developments of new towns are contiguous to the existing urban centers, then, in terms of vehicle kilometers traveled (VKT), there would be a total savings of 744 million km/year. This is equivalent to transportation cost savings of US $255 million per year, including the value of travel time.

Some authors argue that self-containment is better achieved through market forces, rather than planned land uses, and often provide examples of highly self-contained suburban communities in the United States (Downs, 1992; Giuliano, 1991; Gordon et al., 1991). The results of Gordon et al. (1991) supported the utilization of market forces in achieving a jobs–housing balance when arguing that "spontaneous relocation decisions by firms and households do a very nice job of achieving balance, and of keeping commuting times within tolerable limits without costly planning interventions" (page 419). Similarly, Clapson (2002) investigated the two new-town examples of Reston, Virginia, USA, and Milton Keynes, England. He argued that the original intentions of planners to build compact and self-contained new towns have not been fulfilled because of the preference of new town residents for low-density housing.

Jun (2012) explored the effects of Seoul's new-town development on suburbanization and mobility. In his study, he took a counterfactual approach to the benefits and detriments of new-town development by evaluating what Seoul might look like if new-town development had never occurred. It involved evaluating variable urban spatial structures and citizen mobility in scenarios with (baseline scenario) and without the presence of New Towns. This approach made it possible to subtract the singular effects of Seoul's New Town development from the current urban environment while controlling other factors that shape the urban area. He utilized random-utility-based location choice models, based on random-utility theory, to explain location behaviours of urban residents (see Wegener, 2004). From previous similar studies for Seoul, this study was different in terms of two modifications: the system of land-use zones, disaggregating them from twenty-three to seventy-four zones; and in terms of transforming the structure of the model, from residential-location choice (fixed employment location) to a module of employment-location choice (fixed residential location).New Town development in Seoul is highly associated with residential location, rather than with employment location. This enabled the estimation of the effects of New Towns on the journeys from home to work (commuting trips), and to shop (shopping trips). He found that substantial suburbanization is driven by the development of the new suburban towns, as well as both positive and negative consequences of new town development. Positive contributions include decreases in travel time in the central city due to the relief of congestion. Negative consequences of suburbanization include longer times of travel for commuting and shopping trips, and increased emission levels.

Another term, the "internal trip capture" is used by various researchers to find the relationship of various physical and socio-economic factors with self-containment (Greenwald, 2006; Yigitcanlar et al., 2007; Ewing et al., 2011; Merlin, 2014). These studies suggest that internal trip capture rises with the size of the geography under study as measured by population or job counts. It rises with increased land-use mix, and declines with proximity of the geography to the regional center. Greenwald (2006) found that higher internal trips are more likely with higher land-use entropy (a measure of the diversity and balance across employment activities) and in the Traffic Analysis Zone of a person's home. Yigitcanlar et al. (2007) did a study of master-planned developments in Australia. He found low levels of self-containment for commuting travel and also noted that self-containment decreases with household car use and increases with distance to the central business district (CBD). Ewing et al. (2011) examined 239 mixed-use developments across 6 metropolitan regions and found that the internal trip capture of developments increased with development size, better jobs–housing balance within the development, and higher development intensity as measured by floor area ratio. His study suggests that jobs–housing balance has the largest influence on internal trip capture rates.

Recently, Merlin (2014) examined various measures of urban form across a range of community scales and tested how these measures relate to completeness with respect to non-work trips and tours. He defines a complete community as a "sub-regional geographic boundary within which most residents are able to meet most of their daily and weekly non-work travel demands". He measured urban form using three types of variables: size and density variables, mixed-use variables (including jobs–worker balance), and accessibility variables, with the dependent variable being "internal tour" or "trip capture". His study concluded that accessibility share is most important variable for predicting community completeness in terms of non-work tours. In addition to accessibility share, other important factors that help in community completeness are level of mixed use (either in terms of jobs–workers balance or in terms of the balance across many different activity types within a community (entropy)). He also found that too many jobs in a community are as problematic for community completeness as too few jobs. He found that other influential factors for community completeness are scale and type of geography, and that planners need to plan for complete communities at a substantially large scale, rather than on neighbourhood scale (Merlin, 2014).

The Greater Toronto-Hamilton Area (GTHA) is the major urban centre of Canada. In the last few decades, many thriving suburban areas have emerged in the region. However, there is lack of more recent studies exploring how self-contained these new emerging suburban area are and how commuting patterns and distances have changed, considering both place of work and place of residence. In this chapter, descriptive analysis on commuting patterns of workers and commuting distances at the Census Sub-Division level in the GTHA has been conducted.

Specific objectives of this descriptive analysis are:

(i) To determine how self-contained are the various communities in the GTHA and how their residents and workers commute

(ii) To explore the differences in commuting patterns in various communities, and analyse travel pattern information in the GTHA.

2.2. Methodology

2.2.1. Study Area & Data

The geographical area under study is the GTHA, constituting the City of Toronto, the City of Hamilton, and regional municipalities of Durham, Halton, Peel and York. There are a total of 26 local regions known as Census Sub-Divisions (CSDs) in the study area. The primary data source is the Transportation Tomorrow Survey (TTS) for the year 2011. TTS is a comprehensive travel survey conducted in the Greater Toronto and Hamilton Area once every five years (Transportation, 2011). The survey addresses questions about the household, about each person in household, and about each trip made by each person the previous day. In addition, a full 24 hour travel diary for each household member is collected, showing how and where people travel. Therefore, the database used for this study consists of three levels of information, related to *Household*, *Person* and *Trips*. The Toronto region comprises of Planning Districts 1 to 16 in the TTS database.

The TTS data used in this study is a 5% sample, and expansion factors provided along with the data have been used to represent the population where necessary. The data was aggregated at Census Sub-Division level from Traffic Analysis Zones to analyse various statistics of municipalities (or CSDs) in the GTHA. Statistics related to population, number of jobs, number of resident employees and average commuting distances of these CSDs have been studied.

Population for the years 2001 and 2006 at the CSD level was obtained from Statistics Canada (2011). The percentage change in the population was estimated as follows:

$$\text{Percentage change} = \frac{(\text{New Population} - \text{Old Population})}{\text{Old Population}} \times 100 \qquad \text{(Eq.1)}$$

To calculate self-containment of resident workers in a CSD, the method used by Statistics Canada (as mentioned above in Chapter 2 - Section 2.1.2) has been utilized here. However, it should be noted that Statistics Canada utilizes a reciprocal approach to measure self-containment, which is defined by two components: the self-containment of workers; and the self-containment of residents. Statistics Canada refers to self-containment as a combination of both of these components. For the purpose of this study, only the percent of resident workers in an area that also work in the same area has been calculated. Selecting this method will provide a simple and clear picture of workers that reside locally in their Census Sub-Division. A similar approach has also been used by Cervero (1989) for calculating the percentage of locally residing workers.

Resident Employees in this study represent only those that commute from home to work using any mode of travel. For the resident employees in a CSD, the number of resident employees in a particular TAZ was obtained from TTS data. The full-time and part-time employees in the sample are expanded based on the Expansion Factors given with the

TTS data, and the results are summed at the CSD level. Similarly, the number of jobs for the CSDs were obtained by expanding and aggregating the jobs available for TAZs.

The average commuting distances for both the place of residence and place of work have been calculated for each CSD as shown by equations 2 and 3. For this purpose, the number of commuters and their collective commuting distance from TTS dataset were utilized. The average commuting distance calculated separately for both the place of residence and place of work, in order to have a clear picture of the average distance the resident employees from an area cover to go to work, and the average distance the workers of an area cover on a daily basis.

Average Commuting Distance for Place of Residence =

$$\frac{\Sigma\ (\text{Commuting distance of all employed residents originating from a CSD})}{\text{Number of employed residents originating from a CSD}} \qquad \text{(Eq. 2)}$$

Average Commuting Distance for Place of Work =

$$\frac{\Sigma\ (\text{Commuting distance of all workers coming to a CSD})}{\text{Number of workers coming to a CSD}} \qquad \text{(Eq. 3)}$$

2.3. Results and Discussion

According to data from Statistics Canada (2011), the population of GHTA is 6.5 million, with around 1.9 million being employed according to TTS data. Information on jobs, resident employees and population is shown in Figure 2-1.

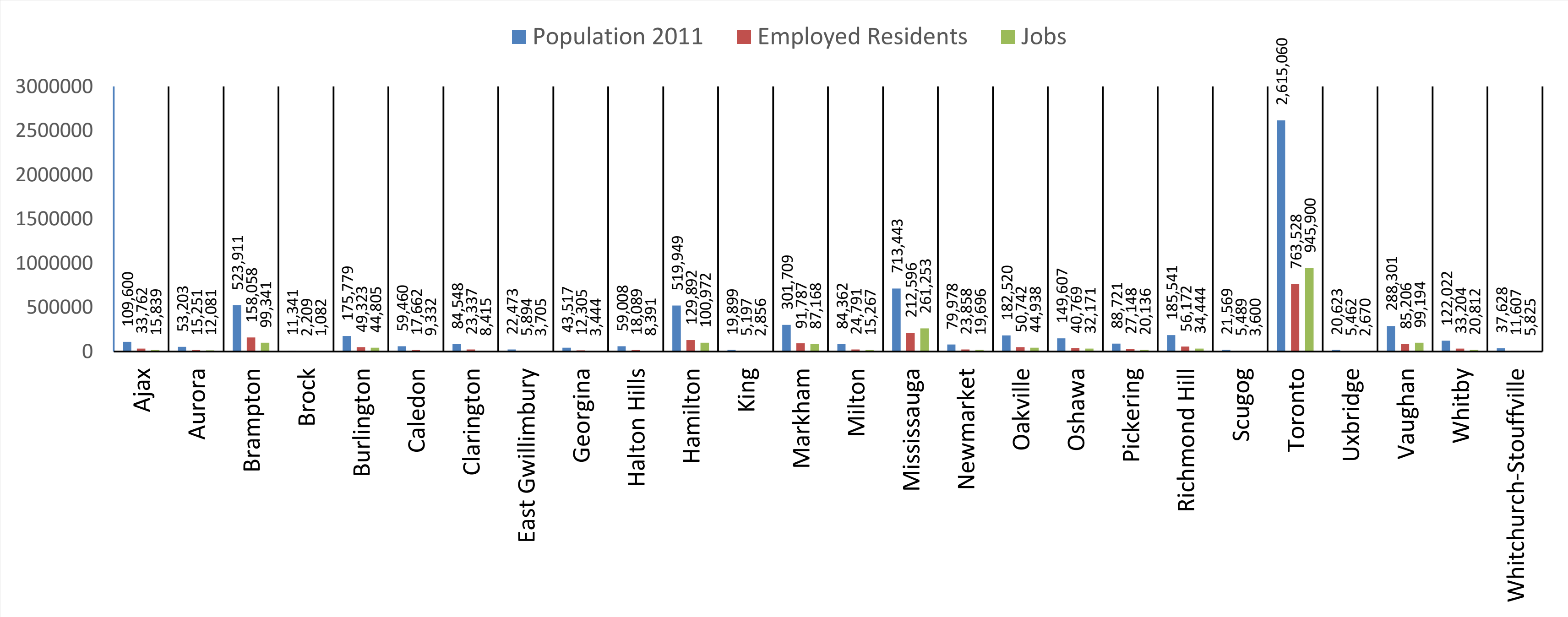

Figure 2-1: Population, employed residents and jobs in CSDs in the GTHA.

Table 2-1: CSDs in study area and their population statistics.

CSD NAME	CSD TYPE*	Population change % (2006 - 2011)	Jobs to Employed Residents Ratio	Resident Employees (Rel. Freq.)	Jobs (Rel. Freq.)
Ajax	T	21.6	0.47	1.77%	0.83%
Aurora	T	11.7	0.79	0.80%	0.63%
Brampton	CY	20.8	0.63	8.30%	5.22%
Brock	TP	-5.3	0.49	0.12%	0.06%
Burlington	CY	6.9	0.91	2.59%	2.35%
Caledon	T	4.2	0.53	0.93%	0.49%
Clarington	MU	8.6	0.36	1.23%	0.44%
East Gwillimbury	T	6.7	0.63	0.31%	0.19%
Georgina	T	2.8	0.28	0.65%	0.18%
Halton Hills	T	6.7	0.46	0.95%	0.44%
Hamilton	C	3.1	0.78	6.82%	5.31%
King	TP	2.1	0.55	0.27%	0.15%
Markham	T	15.3	0.95	4.82%	4.58%
Milton	T	56.5	0.62	1.30%	0.80%
Mississauga	CY	6.7	1.23	11.17%	13.73%
Newmarket	T	7.6	0.83	1.25%	1.03%
Oakville	T	10.2	0.89	2.67%	2.36%
Oshawa	CY	5.7	0.79	2.14%	1.69%
Pickering	CY	1.0	0.74	1.43%	1.06%
Richmond Hill	T	14.0	0.61	2.95%	1.81%
Scugog	TP	0.6	0.66	0.29%	0.19%
Toronto	C	4.5	1.24	40.12%	49.70%
Uxbridge	TP	7.6	0.49	0.29%	0.14%
Vaughan	CY	20.7	1.16	4.48%	5.21%
Whitby	T	9.7	0.63	1.74%	1.09%
Whitchurch-Stouffville	T	54.3	0.50	0.61%	0.31%
TOTALS				100%	100%

* T: Town, C: City, CY: City, TP: Township, MU: Municipality.

The largest number of people live in Toronto (2.6 million), followed by Mississauga (0.7 million), Brampton (0.5 million) and Hamilton (0.5 million) (Figure 2-1). Table 2-1 shows that Toronto observed a 4.5% change in population over five year period from 2006 to 2011. However, there are areas like Ajax, Milton and Whitchurch-Stouffville that observed higher percentage change in their population over the 5 year period, but their original population was quite small to begin with as compared to Toronto. A decrease in population was observed only for the township of Brock (5.3%).

Table 2-1 also provides the relative frequency of employed residents and jobs in a particular region with respect to the whole study area. For employed residents, relative frequency is obtained by dividing the total number of employed residents in one region by the sum of employed residents in all regions, and converting the result to percentage. In the same way, the relative frequencies of jobs in each area have been calculated. It shows that Toronto accounts for 40.1% of employed residents of whole study area, while 49.7% of jobs in whole study area are in Toronto. Mississauga has 11.2% of employed residents and has 13.7% of jobs with respect to total counts in GTHA. This gives a very clear picture of economic activity going on in Toronto. Other areas like Brampton and Hamilton have high relative frequency in terms of employed residents and jobs. However, they are very small as compared to Toronto.

At the CSD level, the ratio of jobs to employed residents is shown in Table 2-1. A value of jobs to employed residents' ratio closer to 1 shows that the area is balanced in terms of jobs and employed residents. However, this does not mean that an area is self-contained as well. It can be seen from jobs to employed residents ratios that Toronto (1.24), Mississauga (1.23) and Vaughan (1.16) have more jobs than the resident employees.

Figure 2-2, Figure 2-3 and Figure 2-4 show densities of jobs, resident employees and population in each CSD. Jobs density and resident employees' density per square kilometer are very high in Toronto. The Toronto CSD is geographically located in the centre of these high jobs and high resident employees CSDs or areas. Spatially, the values decrease as one moves away from Toronto CSD to suburban areas. The highest jobs density was observed in Toronto (1492 per sq.km), followed by Mississauga (901 per sq.km), Newmarket (515.7 per sq.km) and Markham (408.4 per sq.km). The map of employed resident density shows that Toronto has highest resident employees' density as well (1204.3 per sq.km), followed by Mississauga, Newmarket, Brampton, Richmond Hill and Ajax, ranging from 430.2 to 733.3 per square kilometer. The maps of employed residents density (Figure 2-3) and population density (Figure 2-4) show almost the same distribution visually. However, the actual values of resident employees' density are almost one-third of population density.

Another unique feature shown on these figures is the emergence of new but smaller areas of high population as well as jobs and employee densities such as Richmond Hill, Aurora and Newmarket along a northern corridor. These areas are located on both sides of Highway-404. Higher population density in an area comes with high-density development, which is usually associated with reduced trip lengths (Ewing et al., 2003; Giuliano & Narayan, 2003), and promote more use of use of public transport and walking (Cervero 1996). In contrast, such a developmental pattern was not observed for the Hamilton CSD, which is also well connected with Toronto through major highways and transit. The absence of such a pattern in Hamilton may be due to higher commute distance and commute times from Hamilton to Toronto, which is described and discussed in the following sections.

Overall, high values of employed residents with respect to population in the GTHA are indicative of the dynamic and thriving economic activities in this region. It also shows the importance of connectivity between CSDs and proximity to a large jobs density centre such as Toronto.

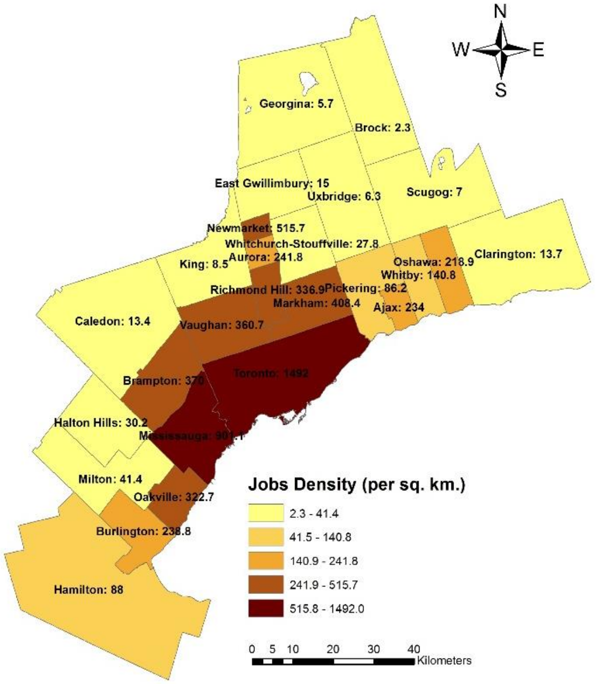

Figure 2-2: Jobs density in CSDs

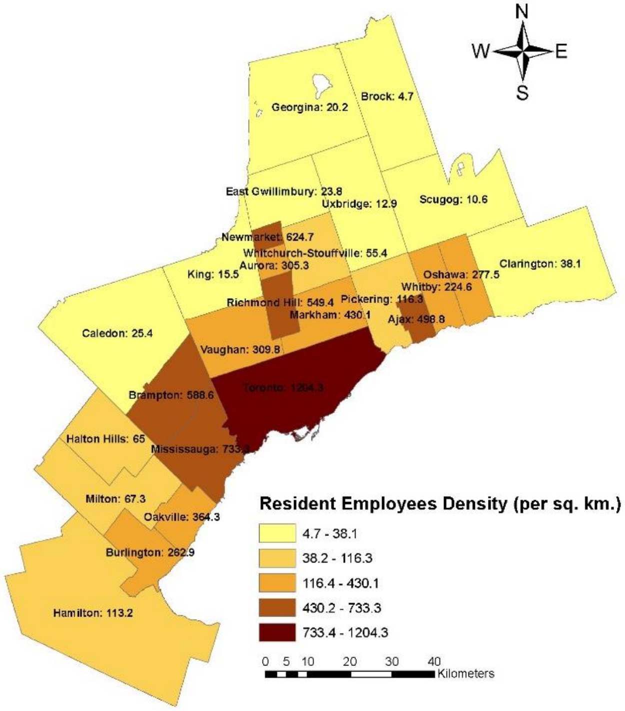

Figure 2-3: Resident employees density in CSDs

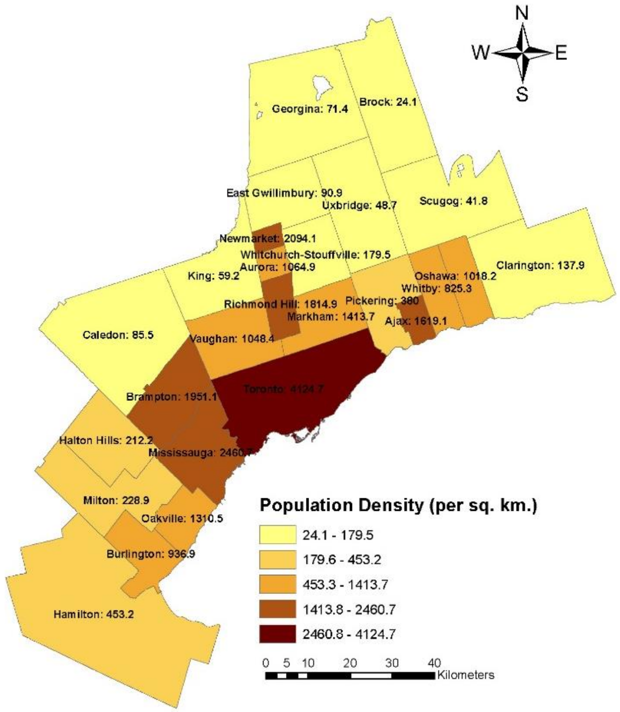

Figure 2-4: Population density in CSDs

2.3.1. Self-containment and Outbound Commute

An appropriate balance between populations, jobs and resident employees of a CSD results in self-containment of an area. It has a major impact on internal and outgoing commute and commuting distances in the region.

Table 2-2 and Figure 2-5 show the internal and outgoing commute for each CSD of the study. The internal commute is indicative of the level of self-containment in an area, while the percentage of outgoing commute shows the number of residents going to other CSDs for work.

In the GTHA, the Toronto and Hamilton CSDs exhibit very high values of self-containment, where 81% and 70% of resident workers commute within their respective CSD. Other emerging self-contained areas include Mississauga, Oshawa, Burlington, Brampton and Scugog, where 51%, 38%, 36%, 36% and 32% resident workers commute within their respective CSD.

In contrast, the highest percentage of outgoing commute was observed for King (92%), East Gwillimbury (87%) and Uxbridge (87%). It shows that King, East Gwillimbury and Uxbridge CSDs are the least self-contained and a very high number of commuters are going to other CSDs for work. The spatial representation of these internal and outgoing commutes is shown in Figure 2-6 and Figure 2-7, respectively. It shows a distinct spatial pattern where areas located in the north and northwest of Toronto are major sources of outgoing commutes. In terms of the actual number of outgoing commuters, Toronto (145,059), Mississauga (103,458), Brampton (101,640), Markham (66,200) and Vaughan (58,858) were the major areas contributing to outbound commutes as shown in Table 2-2.

High levels of self-containment alone cannot be an indicator of economic growth in an area. The attractiveness of an area for workers can be represented by the number of workers commuting to a CSD from other CSDs. Table 2-3 and Figure 2-8 show the amount of commuters coming to a CSD from the whole study area. Inbound commute represents the attractiveness of an area for workers. The highest value is observed for Toronto (37.9%), followed by Mississauga (17.6%), Vaughan (8.4%), Markham (7.1%) and Brampton (5%). If Figure 2-6 is compared with Figure 2-8, it is observed that Toronto is the destination for an additional 37.9% of commuters from the whole study area, whereas Hamilton attracts only 1.2% additional commuters from the total number of commuters in study area. The places with low percentage of commuters coming from other CSDs can be said to have high number of basic jobs. Places with high percentage of commuters coming from other CSDs can be said to have substantial number of non-basic jobs as well, and attracts commuters from outside. It can be suggested that Toronto has a high number of basic as well as non-basic jobs. Hamilton, on the other hand, can be said to have high number of basic jobs that are characteristic of the area, but does not have as many specialized jobs that would attract the workers from far distances.

Table 2-2: Internal and outgoing commute for each CSD.

CSDNAME	Internal Commute	Outbound Commute	Percentage Internal Commute (%)	Percentage Outbound Commute (%)
Ajax	5581	28181	17%	83%
Aurora	3107	12144	20%	80%
Brampton	56418	101640	36%	64%
Brock	472	1738	21%	79%
Burlington	17893	31430	36%	64%
Caledon	3146	14516	18%	82%
Clarington	5437	17900	23%	77%
East Gwillimbury	765	5129	13%	87%
Georgina	2525	9780	21%	79%
Halton Hills	4714	13375	26%	74%
Hamilton	90357	39535	70%	30%
King	432	4765	8%	92%
Markham	25587	66200	28%	72%
Milton	5433	19357	22%	78%
Mississauga	109138	103458	51%	49%
Newmarket	7508	16349	31%	69%
Oakville	14769	35973	29%	71%
Oshawa	15670	25098	38%	62%
Pickering	4419	22729	16%	84%
Richmond Hill	9481	46691	17%	83%
Scugog	1776	3713	32%	68%
Toronto	618469	145059	81%	19%
Uxbridge	716	4746	13%	87%
Vaughan	26347	58858	31%	69%
Whitby	6553	26652	20%	80%
Whitchurch-Stouffville	1940	9667	17%	83%

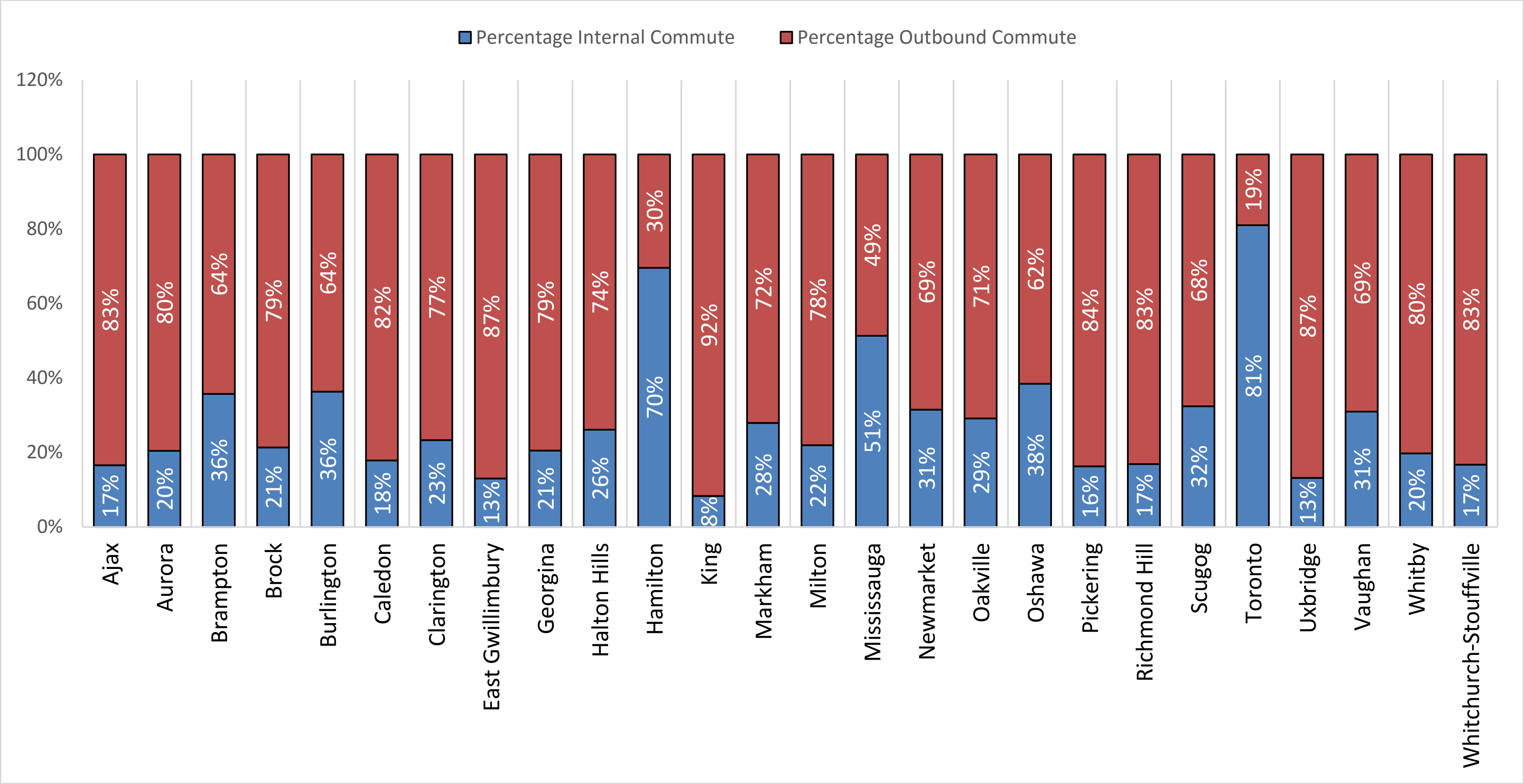

Figure 2-5: Percentage of internal commute and outbound commute for each CSD.

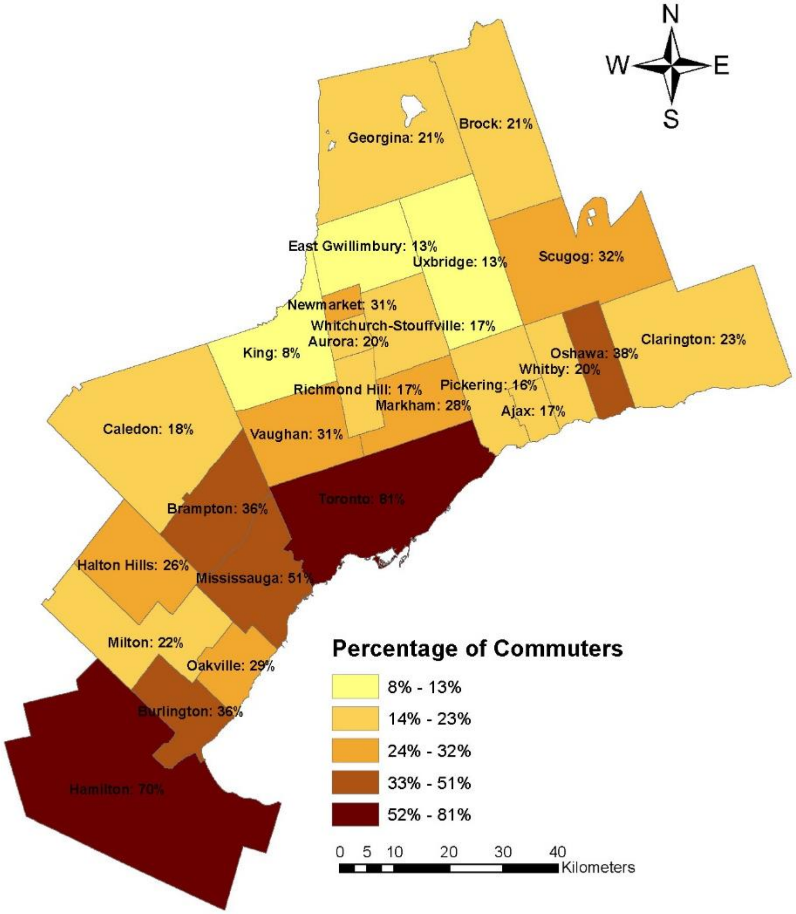

Figure 2-6: Self-containment.

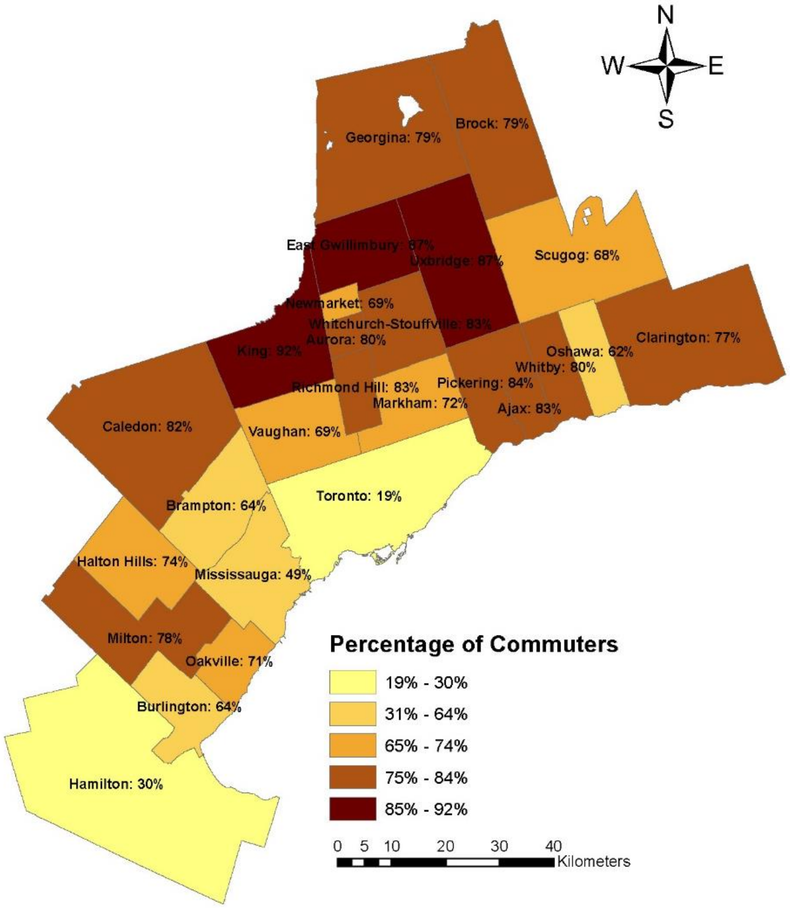

Figure 2-7: Percentage of outbound commute.

Table 2-3: Total Inbound commute and contribution of commuters from other CSDs.

CSDNAME	Total inbound commute	Inbound Commute From Outside	Percentage Inbound Commute From Outside
Ajax	15839	10258	1.19%
Aurora	12081	8974	1.04%
Brampton	99341	42923	4.96%
Brock	1082	610	0.07%
Burlington	44805	26911	3.11%
Caledon	9332	6186	0.72%
Clarington	8415	2978	0.34%
East Gwillimbury	3705	2940	0.34%
Georgina	3444	919	0.11%
Halton Hills	8391	3677	0.43%
Hamilton	100972	10615	1.23%
King	2856	2424	0.28%
Markham	87168	61581	7.12%
Milton	15267	9834	1.14%
Mississauga	261253	152115	17.59%
Newmarket	19696	12188	1.41%
Oakville	44938	30169	3.49%
Oshawa	32171	16500	1.91%
Pickering	20136	15716	1.82%
Richmond Hill	34444	24963	2.89%
Scugog	3600	1824	0.21%
Toronto	945900	327431	37.87%
Uxbridge	2670	1954	0.23%
Vaughan	99194	72846	8.42%
Whitby	20812	14259	1.65%
Whitchurch-Stouffville	5825	3885	0.45%

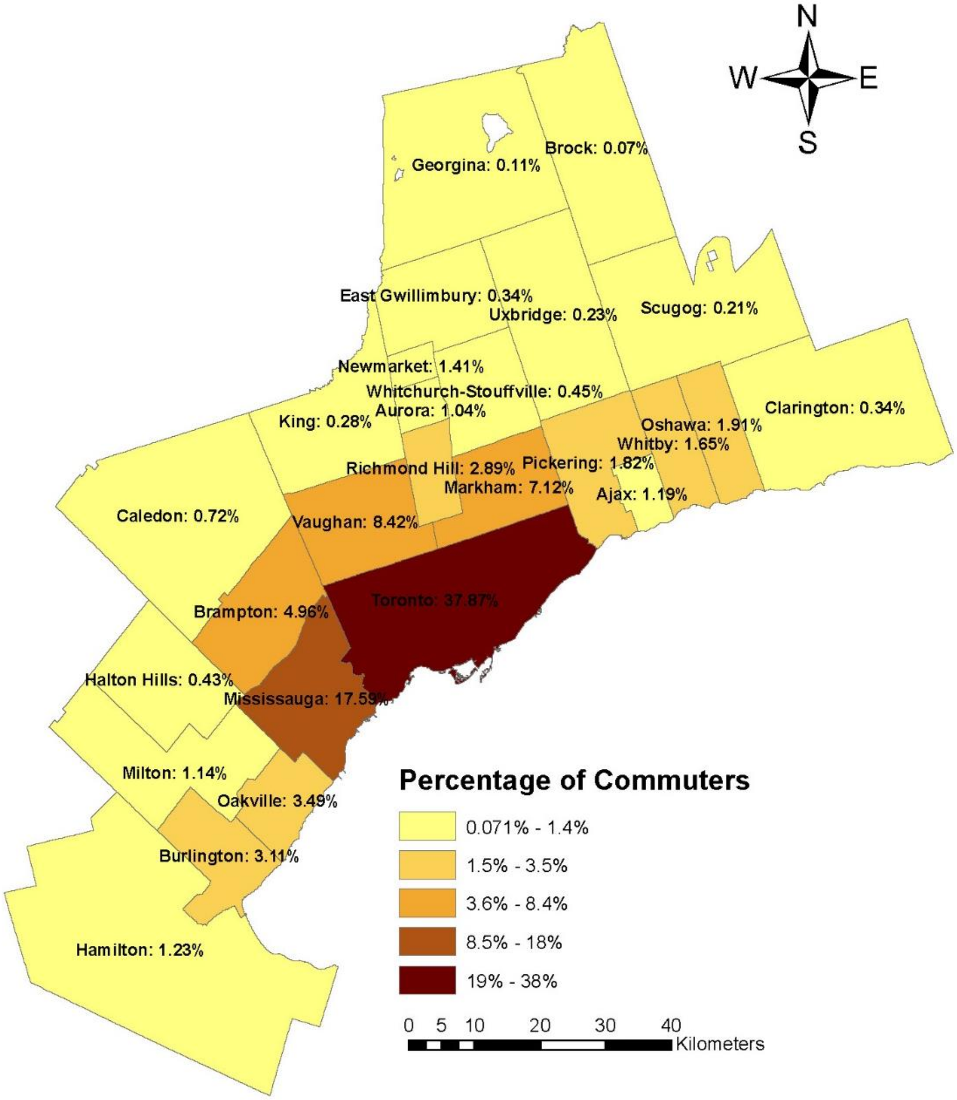

Figure 2-8: Percentage of inbound commute coming from other CSDs.

2.3.2. Average Commuting Distance by Place of Residence and Place of Work

Results showed that CSDs near Toronto exhibit very low commuting distance for both the place of residence and place of work (Table 2-4 and Table 2-5; Figure 2-9 and Figure 2-10). When one moves to areas and CSDs located in the North, Northwest and East of Toronto, the commuting distance significantly increases. This general observation does not apply to the city of Hamilton.

Toronto shows an average commuting distance of 10 km and 14.3 km for the place of residence and place of work, respectively (Table 2-4 and Table 2-5). These relatively small values are probably because of high self-containment in the Toronto area with 81% of residents commuting within the CSD, thereby lowering the commuting distance by both the place of work and place of residence. The same can be said for Hamilton as well, where the average commuting distance is 14.2 km and 8.9 km for the place of residence and place of work, respectively. However, in Hamilton the average commuting distance for resident commuters was higher as compared to commuting distance for work place. These results are in contrast to commuting distances in Toronto and are as expected. The areas adjacent to Toronto CSD like Vaughan, Mississauga, Brampton and Markham, also have a lower average commuting distance for place of residence, ranging from 13.3 km to 14.6 km. Residents of Georgina (32.5 km) and Brock (34.5 km) commuted exceptionally long distances to go to work in the GTHA (Table 2-4; Figure 2-9).

Hamilton (8.9 km) and Oshawa (10.6 km) showed the smallest values for average commuting distance for place of work, showing that workers with jobs in these CSDs commute short distances. Results also show that the workers with jobs in Pickering (15.7 km), Milton (15.7 km), Scugog (16.6 km), Caledon (17.6), Uxbridge (18.6), King (19.3) and Brock (20.8) commute long distances to come to work with respect to other CSDs (Table 2-5; Figure 2-10). Overall, the higher average commuting distances by place of residence in the GTHA ranged from 21.2 to 34.5 km (Table 2-4; Figure 2-9); whereas higher average commuting distance by place of work ranged from 15.4 to 20.8 km (Table 2-5; Figure 2-10).

The amount of commuters going into Toronto with respect to total number commuters originating from each CSD was also calculated (Figure 2-11). Toronto is the largest destination for commuters, attracting 37.9% of total GTHA commuters, as well as 81% commuters from within Toronto itself (Figure 2-8). The origin and destination of these 37.9% commuters from each CSD in GTHA, except Toronto itself, is shown in Figure 2-11. Richmond Hill (45%), Vaughan (46%), Markham (51%), Ajax (52%) and Pickering (55.5%) are among the CDS sending highest number of commuters into Toronto with respect to total commuters coming from these areas. It is also noteworthy that these CSDs are immediately adjacent to Toronto CSD. Research suggests (e.g. see Jun & Hur, 2001) if new developments are contiguous to existing urban centres, then there is high savings in terms of VKT and travel time.

2.4. Summary of main findings

The results from the descriptive analysis show that in terms of locally residing workers, the city of Toronto is highly self-contained, as 81% of resident workers commute within Toronto. Toronto also attracts an additional 37.9% inbound commute from other CSDs. Richmond Hill (45%), Vaughan (46%), Markham (51%), Ajax (52%) and Pickering (55.5%) are the CDS sending the highest number commuters to Toronto with respect to total resident workers emerging from these areas.

Hamilton has the second highest rate of self-containment, as 70% of its resident workers commute within Hamilton. However, unlike Toronto, the inbound commute to Hamilton from other CSDs is only 1.2%.

The highest outbound commute to other CSDs is originating from King (92%), East Gwillimbury (87%) and Uxbridge (87%) CSDs. These areas are located in the north and northwest of Toronto.

Toronto also exhibited the highest jobs density (1492 per sq.km) as well as the highest employed residents' density (1204.3 per sq.km) among all CSDs in the study area. Other areas showing high jobs densities were Mississauga, Newmarket and Markham, ranging from 408.4 to 901 per sq.km, while other CSDs with high employed residents' densities were Mississauga, Newmarket, Brampton, Richmond Hill and Ajax, ranging from 430.2 to 733.3 per sq.km.

On the aggregate level, Toronto, Vaughan, Mississauga, Brampton, Hamilton and Markham CSDs had very low average commuting distance for place of residence, ranging from 10 km to 14.6 km. The CSDs with exceptionally high commuting distance for place of residence were Georgina (32.5 km) and Brock (34.5 km), showing that residents of these CSDs commute exceptionally long distances to work. Overall, the higher average commuting distances by place of residence in the GTHA ranged from 21.2 to 34.5 km. For place of work, average commuting distance was 8.9 km and 10.6 km for Hamilton and Oshawa, respectively, while workers coming to Uxbridge (18.6 km), King (19.3 km) and Brock (20.8 km) commuted very long distances on average to come to work in these CSDs. Overall the higher average commuting distance by place of work ranged from 15.4 to 20.8 km.

The long daily commute in a large metropolitan areas is a major issue, and policy makers continuously try to improve the policies surrounding transportation, land use, and commuting. In order to have a clear picture of contributing factors, and address the third objective of this study, the next chapter deals with statistical analysis for determining major factors affecting commute distance of employed residents of GTHA on a disaggregate level.

Table 2-4: Average commuting distance by place of residence.

CSD NAME	Distance covered by employed residents (km)	No. of commuters	Average Commuting Distance (km)
Ajax	771,620	33762	22.9
Aurora	302,842	15251	19.9
Brampton	2,181,506	158058	13.8
Brock	76,166	2209	34.5
Burlington	900,450	49323	18.3
Caledon	411,008	17662	23.3
Clarington	535,147	23337	22.9
East Gwillimbury	132,928	5894	22.6
Georgina	400,415	12305	32.5
Halton Hills	346,183	18089	19.1
Hamilton	1,842,518	129892	14.2
King	108,145	5197	20.8
Markham	1,344,534	91787	14.6
Milton	525,223	24791	21.2
Mississauga	2,874,500	212596	13.5
Newmarket	443,500	23858	18.6
Oakville	999,799	50742	19.7
Oshawa	780,000	40769	19.1
Pickering	534,759	27148	19.7
Richmond Hill	910,711	56172	16.2
Scugog	139,425	5489	25.4
Toronto	7,643,578	763528	10.0
Uxbridge	155,344	5462	28.4
Vaughan	1,135,400	85206	13.3
Whitby	803,256	33204	24.2
Whitchurch-Stouffville	237,857	11607	20.5

Table 2-5: Average commuting distance by place of work.

CSD NAME	Distance covered by workers	No. of Commuters	Average Commuting Distance (km)
Ajax	190,332	15839	12.0
Aurora	169,961	12081	14.1
Brampton	1,243,098	99341	12.5
Brock	22,538	1082	20.8
Burlington	563,810	44805	12.6
Caledon	163,795	9332	17.6
Clarington	109,112	8415	13.0
East Gwillimbury	56,999	3705	15.4
Georgina	50,824	3444	14.8
Halton Hills	101,083	8391	12.0
Hamilton	899,873	100972	8.9
King	55,040	2856	19.3
Markham	1,236,081	87168	14.2
Milton	240,116	15267	15.7
Mississauga	3,916,710	261253	15.0
Newmarket	280,112	19696	14.2
Oakville	664,456	44938	14.8
Oshawa	342,381	32171	10.6
Pickering	315,732	20136	15.7
Richmond Hill	482,665	34444	14.0
Scugog	59,591	3600	16.6
Toronto	13,542,612	945900	14.3
Uxbridge	49,663	2670	18.6
Vaughan	1,441,657	99194	14.5
Whitby	249,619	20812	12.0
Whitchurch-Stouffville	88,953	5825	15.3

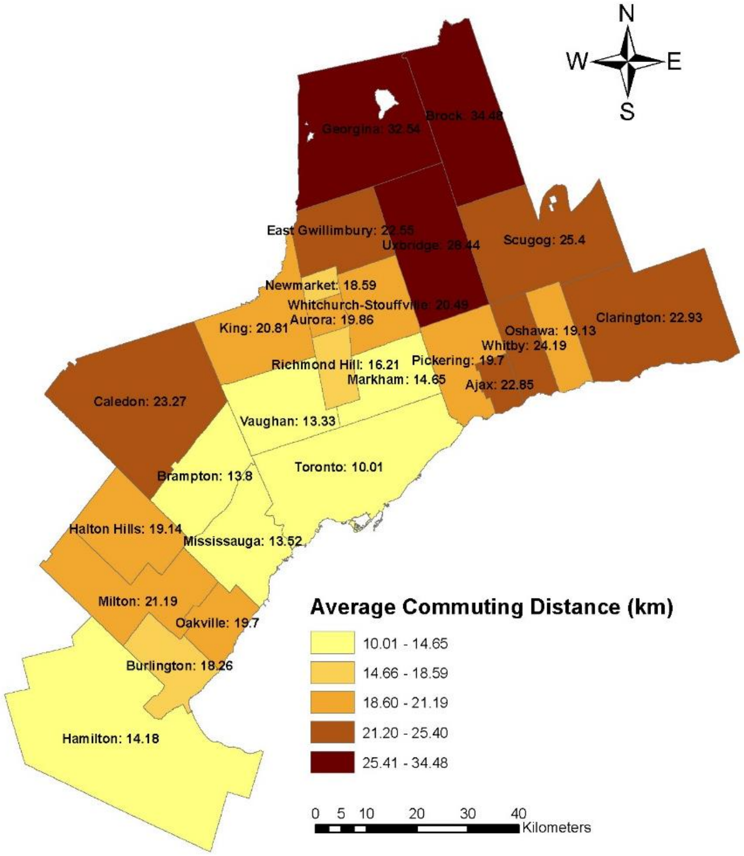

Figure 2-9: Av. commuting distance by place of residence.

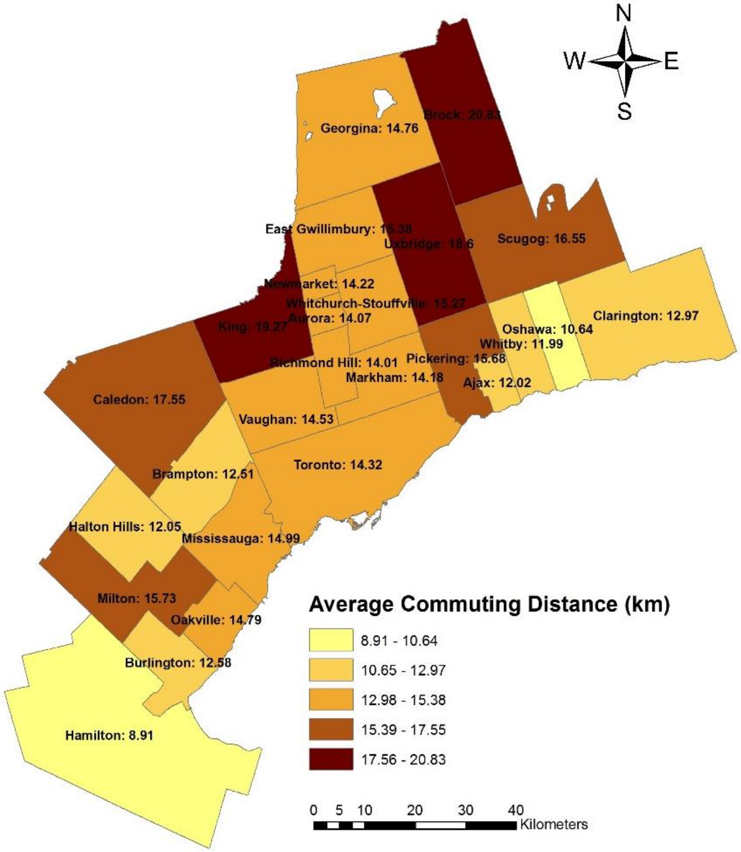

Figure 2-10: Av. commuting distance by place of work.

Figure 2-11: Percentage of commuters from each CSD going into Toronto.

3. DETERMINANTS OF COMMUTING DISTANCE FOR RESIDENT WORKERS IN GTHA

3.1. Introduction and Literature Review

Many researchers have analyzed the causes of the continued lengthening of commuting distances in North American cities (Cervero, 1989; Green (1999); Buliung & Kanaroglou, 2002; Clark & Withers, 2002; Giuliano & Narayan, 2003; Cervero & Duncan, 2006; Green & Owen, 2006; Maoh & Kanaroglou, 2007; Mercado & Páez, 2009; Manaugh et al., 2010; Axisa et al., 2012; Maoh & Tang, 2012; Newbold et al., 2015). They have attributed the increase to a variety of socioeconomic, labour market, travel behaviour, land use, migration and household factors. The socioeconomic factors used in such studies are typically age, gender, income and household attributes. Other factors are related to labour market (e.g. employment status, occupation), land use and urban structure (density, proximity to facilities), travel behaviour (e.g. mode of transportation, possession of license or transit pass) and household attributes (e.g. multi-worker household, auto availability, presence of children).

In general, females are expected to commute shorter distances than males. Several North American studies repeatedly showed the disparity with respect to gender and commute distance, (e.g., Clark & Withers, 2002; Maoh & Tang, 2012; Axisa et al., 2012; Buliung & Kanaroglou, 2002). This consistent difference in commute distance between men and women may be due to a woman's need to align her work with other responsibilities like home and childcare, as proposed by Hanson and Pratt (1991, 1995). Some recent studies, however, show that this difference might be converging for a select number of demographic groups, based on race, age and ethnicity (Crane, 2007; Crane & Takahashi, 2009). However, when this variable is analysed keeping others constant, it shows that men typically travel farther than women.

Age is expected to show a non-linear behaviour with respect to commute distance. Typically an inverted U-shaped relationship is observed in a bivariate relation of age and commute distance. This non-linear behaviour has been reported by Morency et al. (2011) and Axisa et al. (2012) for North American cities. This trend can be attributed towards the low chances of vehicle ownership by young people, as well as more chances of using active modes of transport or doing a part-time job. With increasing age, chances of owning a vehicle and doing a full-time job become higher, giving rise to longer commutes. Full-time employees are expected to commute longer than part-time employees, whereas full-time students are expected to commute shorter than part-time students. Studies by Newbold et al. (2015); Maoh and Tang (2012); Axisa et al. (2012); Morency et al. (2011); Mercado and Páez (2009), and Green (1999) have reported that full-time workers typically undertake a longer commute. The full-time employees obviously have higher wages than part-time employees, and thus the cost-effectiveness of travelling farther to go to work is justified.

Higher income has a pronounced effect on commuting distance as well. People with higher income can afford to commute longer, and they are more likely to own a vehicle. Studies by Green (1999) and Prillwitz et al. (2007) show the positive impact of higher income on longer commutes. Similarly, with respect to occupation-types, people with low skill levels are expected to have a shorter commute because of low wages associated with basic skills. People having specialized skills are expected to earn more, thereby increasing the likelihood of vehicle ownership and increasing the affordability to have a longer commute. Previous studies by Champion et al. (2009) and Green and Owen (2006) show that occupations associated with low levels of skill typically travel shorter than average distances.

Mode of transportation is often analysed in studies of commute distance. Usually, in Canadian cities, the general observation is that people who commute the longest use the automobile as the mode of travel. Examples of such studies are for regions of Windsor

(Maoh and Tang, 2012), GTHA (Buliung and Kanaroglou, 2002) and Hamilton (Mercado and Páez, 2009). Some studies on long distance commuting previously have been done on sprawled cities that consistently show a strong relationship between the use of automobiles and longer commutes (Maoh and Tang, 2012; Dieleman et al., 2002). However, in a recent study by Newbold et al., (2015) in Ontario's Greater Golden Horseshoe, the mode of transportation showed almost the same impacts on commute distance of respondent using transit or using vehicle as an auto driver. Overall, most of the previous studies in the GTHA and other North American cities show that auto mode of travel usually dominates as the main characteristic of long distance commuters.

Owners of a driver's license are expected to commute longer distances (Mercado & Páez, 2009). Owing a vehicle makes the chances of a longer commute even greater. Past studies (Cervero & Duncan, 2006; Dieleman et al., 2002; Schwanen et al., 2004; Manaugh et al., 2010; Morency et al., 2011; Sultana & Weber, 2007; Watts, 2009; Mercado & Páez, 2009) have shown a positive relationship of vehicle ownership to commute distance. In addition, these studies show that presence of vehicles in the household result in an increasing chance of longer commute. In contrast, the households may not have as many vehicles as the number of license holders, so the one-to-one relationship between number of vehicles and number of license holders is rarely the case. Thus, an increasing number of license holders in a household is expected to result in a decreasing commuting distance to go to work.

Possession of a transit pass is also an important variable to consider. The Greater Toronto and Hamilton Area currently operate eight local transit systems and a regional transit service. Local transit systems include Brampton Transit, Burlington Transit, Durham Region Transit, Hamilton Street Railway (HSR), Mississauga Transit (MiWay), Oakville Transit, Toronto Transit Commission (TTC), and York Region Transit (YRT) & VIVA. GO Transit – a division of Metrolinx – is the regional public transit service for the GTHA. The buses and trains operated by GO Transit carry over 65 million passengers a year. People with possession of this regional transit pass are expected to have a longer commute, relative to people with local transit passes.

Household structures greatly affect the commute distance of people. Having no children in the household gives a person the choice to relocate very easily to be near the place of work, and thus reduce his/her commute distance. Parents usually prefer to raise young families in suburban locations, but such locations generally come with longer commute distances. Recent literature shows that people with no children in the household exhibit the shortest commute distance; those with younger children have longest commute; and those with older children, e.g. aged 10-12, have shorter commute than those with very young children (Axisa et al., 2012). Past studies have also shown that females with younger children commute shorter distances, as per household responsibility hypothesis, which states that employed women are likely to undertake shorter trips in order to manage both the household and work responsibilities (White, 1977; Blumen & Kellerman, 1990; Johnston-Anumonwo, 1992; Buliung & Kanaroglou, 2002).

Population density (number of persons in the zone relative to its area) has been traditionally used in travel behaviour analyses (e.g., Cervero & Kockelman, 1997; Morency et al., 2011; Limtanakool et al., 2006). A higher population density in an area is expected to shorten the commute distance for residents of such areas. High-density development can reduce the trip lengths (Ewing et al., 2003; Giuliano & Narayan, 2003), and promote the use of public transport and walking (Cervero 1996).

The spatial variable "Distance from CBD" is often used in literature on commuting, location attributes, and travel behaviour analysis (Miller & Ibrahim, 1998; Yigitcanlar et al., 2007; Morency et al., 2011). As the distance from the CBD increases, the commuting distance is also expected to increase. While studying the interrelationship between urban form and work trip commuting efficiency in greater Toronto area, Miller and Ibrahim (1998) found that the VKT per worker increased as one moved away from central core of city, from other high density employment centres within urban area, or both. Yigitcanlar et al. (2007) studied travel self-containment in six Master Planned Estates (MPEs) in Australia. They found that for each kilometre increase in the distance from the MPE to the CBD, the self-containment rate increased by 0.2 per cent. The reason for this positive correlation between travel self-containment and distance from the CBD was that the MPEs were located on metropolitan fringes, and at greater distance from the CBD, they become more dependent for employment on local and regional activity centres and less dependent on the metropolitan CBD.

According to many researchers, residence in a mixed-use area curbs commute distance. The jobs-housing balance has been the focus of studies since people started to live in suburbs of major cities at the beginning of the 20th century, while working in city cores. At the same time, the use of personal vehicles also increased for commuting purposes. As suburbs further expanded and more and more people started to commute to and from suburbs, a dramatic increase in commuting time and commuting distances emerged, with the increase in commuting times mainly due to congested road networks. Eventually these factors caused declines in job accessibility. Many empirical studies have reported these changes (Downs, 1992; Gordon et al., 1991; Levinson and Kumar, 1994).

Many researchers suggest that commuting distances and times are increasing and that the negligence of polices related to maintaining jobs and housing balance may result in negative consequences in terms of commuting, environmental problems and self-containment of an area (Cervero, 1989, 1991; 1995a; 1996; Cervero & Wu, 1998; Rosetti & Eversole, 1993; Frank & Pivo, 1994; Levinson & Kumar, 1994; Ewing, 1995a; Jun & Hur, 2001; Zhao et al., 2011; Miller, 2011). In contrast, others argue that jobs-housing balance does not matter in shaping regional commute (Giuliano, 1991, 1995; Downs, 1992; Wachs et al., 1993; Lowry, 1998; Gordon et al., 1991). According to these researchers, the jobs-housing balance is attained automatically over time as per the co-location theory, and market forces play their role in maintaining this balance over time.

A true balance of jobs and housing implies that workers would attain jobs within a reasonable commuting distance from their residence. The concept of jobs-housing balance in the planning context originated from the ideal concept of self-contained community (Howard, 1902; Munford, 1968). The self-contained or balanced community is one where residents can both live and work within the community. However, the concept of jobs-housing balance refers to "distribution of employment to the distribution of workers within a given geographical area" (Giuliano, 1991).

Researchers who found that commuting times and distances are increasing over time have suggested that regional mobility is highly affected by jobs-housing imbalances. Cervero (1989; 1991; 1996) and Cervero and Wu (1998) have examined the way jobs–housing balance and self-containment of employment centers (or cities) affect commuting patterns and housing choices. For example, Cervero (1989) examined how jobs-to-housing ratios in major suburban employment centers (SECs) in the US are related to travel behavior and local traffic conditions. He focussed on factors affecting the distances between where people live and where they work. He also analysed how jobs-housing imbalances have affected levels of regional mobility. Cervero argued that achieving true balance requires a match-up between job opportunities and skill levels of local residents, as well as worker's earnings and local housing prices. His study concluded that improving the balance between jobs and housing may promote less commuting demand.

There are various factors that promote the jobs-housing imbalance, including the lack of regional planning (Cervero, 1996) and various economic and demographic factors that impede the ability of people to reside near their workplace. These include fiscal and exclusionary zoning, growth moratoria, worker earnings/housing cost mismatches, two wage-earner households, and job turnover (Cervero, 1989). Cervero (1989) suggested that continued lengthening of commuting trips is attributed to a widening jobs-housing imbalance in metropolitan areas in both North America and Europe. He found that in the greater Chicago area, the lack of affordable housing near suburban job centers lies at the heart of the region’s jobs-housing imbalance problem. He also studied the factors affecting residential locations of workers residing outside their immediate employment area. For this purpose, he expanded the structure of the basic gravity model to incorporate various pull and push factors in describing jobs-housing relationships. Cost and availability of housing were found to be among the most important factors that shape the residential locational choices of suburban workers. In suburban employment areas, single family homes are costly and such residentially zoned lands are in short supply, so workers are forced to move out of such suburbs. Thus, secular and market forces that affect the supply and cost of housing, along with restrictive zoning practices, are major contributors to the rift between where people live and where they work in suburban labor markets (Cervero, 1989).

Cervero (1995a) focused on the level of self-containment of new towns, the commuting patterns of residents and workers, and differences in levels of internal (within community) commuting and travel times in these communities. He also focused on whether or not the new towns are contributing a relatively high portion of commuting by modes other than the drive-alone automobile such as walking, biking, ride-sharing and transit, compared to surrounding communities (Cervero, 1995a). He noted that in the New Towns in Europe, such as Stockholm, there was an inverse relationship between self-containment and transit commuting (Cervero, 1995a). His analysis revealed that jobs-housing balance, self-sufficiency and self-containment matter little in shaping commuting choices of New Town residents and workers. More important are factors like proximity of new towns to major urban centers and the quality of regional transit services. In Europe, mostly central governments sponsor new town developments. However, in North America, the trend is different, as new communities are mostly built by private real-estate developers seeking to sell homes to predominantly middle-income families who are in search of spacious, rural-like environments that are within commuting distance of metropolitan centers (Cervero, 1995a). These residents are willing to commute long distances, while maintaining their large suburban residences, forcing cities and governments to heavily invest in road networks to meet increases in traffic flows and to reduce congestion. Cervero (1996) questioned whether the cities have naturally evolved into more balanced and self-contained places. He also questioned the implications for commuting. He noted that imbalances in jobs and housing generally worsened in job-surplus cities. While jobs followed labor markets, housing capital generally did not follow jobs. Therefore, one of the major consequences is that workers in job-surplus cities experience long duration of commutes, more vehicle miles travelled per person, and higher rates of solo commuting. Cervero (1996) concluded that these outcomes are more of a planning failure than a market failure. Even if a jobs-housing balance is attained, whether through government authorisation or market forces, it does not guarantee self-containment or reduced external commuting.

Rosetti and Eversole (1993) used census data from 1980 to 1990 to show that mean commute times increased in 35 of the 39 metropolitan areas having populations over one million as of 1990. In one study using 1989 travel data from the greater Seattle-Tacoma region, Frank and Pivo (1994) found that travel distances and travel times are shorter for commutes to balanced areas in the region.

Levinson and Kumar (1994), however, found that congestion and commuting distance have increased but commuting duration has stayed the same. Ewing (1995a) computed the proportion of work trips that remained within more than 500 cities and towns in Florida, US. He found that the share of “internal,” or within-community commutes significantly increased with greater balance between the number of local jobs and working residents.

Jun and Hur (2001) estimated the commuting costs associated with new-town development in Seoul Metropolitan Area (SMA), South Korea. In 1971, a 10 kilometers wide Greenbelt was introduced around Seoul. From 1989 – 1995, five new towns were constructed accommodating 1.16 million people within 50 km^2 of Seoul. The construction of these new towns stabilized the rising housing prices within the Greenbelt. However, there was major criticism on the implications of this construction, including construction pace, development scale, and location of new towns that had accelerated urban sprawl and created social costs of sprawl such as longer commuting distance. The Korean government started to deregulate the Greenbelt and announced a release of around 13 km^2 of SMA's greenbelt for residential development by 2001. Jun and Hur (2001) estimated commuting costs of the "leap-frog" new town development in SMA, which was caused by Seoul's greenbelt. The estimates of commuting distance savings are regarded as a measure of the commuting costs of the "leap-frog" new town development. They concluded that if locations of development of new towns are contiguous to the existing urban centers, then there is significant saving in terms of travel costs. Average commuting distance would be shortened by 1.5% for every worker of the Seoul Metropolitan Area if 196 thousand workers and 420 thousand residents in new towns had been relocated into hypothetical new towns. In terms of vehicle kilometers traveled (VKT), there were a total savings of 744 million km per year, or equivalent to transportation cost savings of US $255 million per year, including the value of travel time.

In similar context, Zhao et al. (2011) investigated jobs-housing balance in Beijing, China, and showed that the jobs-housing balance has a statistically significant association with a worker's commuting time when the factors of transport accessibility, population density and worker's socioeconomic characteristics are controlled (Zhao et al., 2011).

While studying jurisdictions in Virginia, US, Miller (2011) performed correlation and longitudinal analyses and found that jobs-housing balance was highly correlated with shorter commute times.

Some researchers say that residential location choice is affected by many factors in addition to jobs accessibility, such as quality of schools, neighborhood quality, availability of parks and other amenities, racial and ethnic mix and microclimate characteristics (as cited in Giuliano, 1991, p. 308). They also argue that potential transportation and environmental benefits of jobs-housing balance are likely to be minimal, and question whether the jobs-housing balance will ever be an effective tool for producing significant transportation and air quality benefits (Giuliano, 1991, 1995; Downs, 1992).

Gordon et al. (1991), Wachs et al. (1993) and Giuliano (1991) found that commuting times and distances either decreased or stayed fairly constant, and that imbalances usually erode over time. Lowry (1988), Gordon et al. (1991) and Downs (1992) suggested that planning interventions aimed at achieving the jobs-housing balance are not needed, since market conditions naturally bring about the regional balance. They argue that jobs and housing co-locate in order to maintain equilibrium in average commuting times, and it is consistent with time-budget theory, or co-location theory. An example of this type of equilibrium through co-location can be seen in the migration of jobs to the suburbs during the twentieth century, resulting in polycentric urban structures. However, it should be noted that in the case of frequent jobs turnover, the ability to relocate the residence very frequently is reduced. Downs (2005) compared a highly imbalanced scenario in terms of jobs-housing balance, with a balanced scenario for a hypothetical city to see the impacts of regional commute. His results showed that the largest reduction in regional commute was observed to be only 9.5%. He concluded that even very dramatic changes in jobs-housing balance have very low effect on VMT.

Giuliano (1995) suggested that connection between land use and transportation is not as strong and interdependent as many believe it to be. She said that only direct policy regulations for a certain problem would provide an efficient solution to that problem. For example, if we want to reduce environmental damage due to automobile usage, we should directly regulate the auto-related prices and usage, instead of focussing on land use and trying to indirectly affect the problem of transportation. She also looked into the reasons as to why people have longer commutes than the standard theory predicts, and studied various parameters including the jobs-housing mismatches (prices or other factors making the housing area unsuitable for workers having jobs in that area) and jobs-housing imbalances (number of workers that can be housed in an area differs from number of jobs in that area). She found that there is more excess commuting close to city centres where jobs and housing are balanced, instead of areas further from city centre. While studying mismatches, the expected result was that if affordable housing is near the workers' jobs, they will have shorter commute. The tested models however suggested an increment of only 20% commute in both cases, implying that jobs-housing imbalance or mismatch does not satisfactorily explain a large portion of observed commuting patterns.

Many studies have focused on the determinants of commuting distance. However, studies focusing on the determinants of extreme commuting are quite rare. In the United States, Marion and Horner (2007) explicitly modeled the characteristics of extreme commuters, defined by those who travel one way for more than 90 minutes. Champion et al. (2009) analyzed the characteristics of extreme commuters in the UK. In Canada, Maoh and Tang (2012) investigated the significant factors explaining 'normal' and 'extreme' commuters in Windsor, Canada. They considered land use variables such as entropy index and location quotient in the Windsor area in their study. Although the findings from one urban area are not necessarily similar to findings in another area, it is useful to estimate commute distance of normal and extreme commuters for a contiguous region like GTHA, which is very different in urban form from a sprawled city like Windsor. Increasing commuting distances and extreme commuting is a major issue in the GTHA, which is becoming more critical with the increase in population and changes in land use and socioeconomic conditions (Smale, 2014).

This chapter explores various factors affecting commuting distances of normal and extreme commuters in the GTHA. In particular, it considers the ratio of jobs to employed residents and commuters from resident-rich and jobs-rich areas.

Specific objective of this study is to determine which travel behaviour, socioeconomic and labour market factors affect the commuting distance of workers in the GTHA, and whether or not a balanced ratio of jobs to employed residents contributes towards curbing the commute distance.

In the literature, two methods are usually used to examine commuting time or commuting distances. First is a zone-based, aggregate method which analyses commuting time in relation to a given spatial unit, such as residential block, census tract or traffic analysis zone (Wang, 2001). The other method is to examine commuting time or distance is the disaggregated method, which analyses commuting time at the individual worker or household level. The disaggregate approach has been widely used to determine the real commuting situation for individual workers (Cervero & Duncan, 2006; Ewing, 1995b; Stead, 2001; Zhao et al., 2011). This study will use the disaggregate approach, while calculating numerous variables (such as JER, population density, median income of individuals) at the TAZ level.

3.2. Methodology

3.2.1. Study Area and Data

The geographical area covered in this study is the GTHA, an area that includes the City of Toronto, the City of Hamilton, and other cities and suburban areas. The GTHA is the largest urban area in Canada and is considered one of the major urban centres in North America as well. This area has a unique geographical setting because it is located along the shores of Lake Ontario, and is a significant part of the Greater Golden Horseshoe (GGH) region. Rapid growth in population and economic activities in the last few decades have resulted in many suburban areas where a majority of workers now live, while working in the downtown areas of both Toronto and Hamilton. There have been profound changes in the ratio of jobs to employed residents (JER) in the region, resulting in significant increase in commuting distances of workers in the region.

Several datasets are employed to study the determinants of normal and extreme commute distance in GTHA. The primary data source is the Transportation Tomorrow Survey (TTS) for 2011. The survey area is subdivided into traffic zones based on the planning needs of the participating agencies. The Traffic Analysis Zone (TAZ) is a polygon which typically falls along the centre line of roads or the natural geographic boundaries. It is the finest level of spatial aggregation available through Internet Data Retrieval System (Transportation, 2011).

The dataset acquired from TTS is a 5% sample of the entire population and expansion factors have been provided by the TTS along with the data to represent the population. This dataset contains many socioeconomic variables including the commute distance and the mode of transportation used to commute to work. The commuting distance in the dataset had been rounded off to whole numbers, however, for the proposed analysis, the desired level of measurement of this variable was in ratio form. Therefore, this variable was recalculated as the Euclidean distance between the respondent’s usual place of residence and their usual place of work at the TAZ level. The respondent’s commute distance is capped at maximum of 90 km.

Some additional data at the TAZ level are also used in the analysis. These data include the number of jobs in each TAZ. The jobs data are based on the available records from InfoCanada 2011. These data were aggregated at the TAZ level using ArcGIS software. This dataset was utilized to calculate the employers (count of companies) and employees (count of workers in each company) information for each TAZ in the GTHA.

The population data and median income of individuals is acquired from Statistics Canada (2011) at the census tract level, and recalculated at TAZ level. Details of these calculations are discussed later in this section.

For this analysis, the data was required in a format where the one-way work trips of employees aged 15 years and older are considered. A subset of TTS dataset was made by considering all home-to-work trips of employed persons. There were in total 90,939 records in this dataset.

3.2.2. Statistical Analysis and Data Specification

Multiple Linear Regression is used for the identification of factors determining commuting distance in the region. Commuting distance was analyzed as a function of various explanatory variables related to socioeconomic, labour market, travel behaviour, household structure and TAZ characteristics. In total, five models have been tested to determine the factors affecting commuting distance of resident workers in the GTHA. These models are described in Table 3-1.

Table 3-1: Dataset specification for models used in the study

Models	Dataset Specification
Model 1	Finalized dataset of home-to-work trips of commuters older than 15 years of age (84,440 observations).
Model 2	Subset of original dataset to model for normal commuters (65,037 observations).
Model 3	Subset of original dataset to model for extreme commuters (6,628 observations).
Model 4	Subset of original dataset for commuters from resident-rich areas (5,057 observations).
Model 5	Subset of original dataset for commuters from jobs-rich areas (8,740 observations).

This study quantitatively analysed the factors determining commuting distances for GTHA commuters using multivariate regression analysis. However, the reader is warned about the anticipated presence of spatial autocorrelation of flows in this analysis. The commonly used statistical methods often assume that the measured outcomes are independent of each other. If autocorrelation exists, then this violates the fact that observations are independent from one another.

Usually autocorrelation is observed for time-series data, where one time period is almost invariably related to values in adjoining time periods. Spatial autocorrelation exists where high degree of dependency among observations in a geographic space is observed. This occurs when the relative outcome of two locations is related to their distance. It can be detected by using statistical tests like Moran's I or the Durbin-Watson test.

In this analysis however, there are many observations that correspond to the same origin-destination TAZs, therefore commuters from such TAZs are associated with the same commuting distance. This can create significant problems of autocorrelation of flows in the dependent variable and error term. This is different from spatial autocorrelation of distance or time-series data, as mentioned above. Different analyses and measures of spatial autocorrelation are given by Anselin and Ray (2010). However, any such measure is not implemented in this thesis work, and can be further analysed in future.

3.2.2.1. Dependent Variable

One-way average commuting distance has been calculated between origin and destination of employed persons using Euclidean distance between the centroids of TAZ of residence and TAZ of employment as shown in Figure 3-1. This one-way average commuting distance (in km), denoted by d_n for worker n on a typical day can be regressed against a number of explanatory variables X_n:

$$d_n = \beta_0 + \beta_1 X_{n1} + \beta_2 X_{n2} + \ldots + \beta_k X_{nk} \qquad \text{(Eq. 4)}$$

where the *X's* are variables that reflect demographic, household and employment characteristics for individual *n*, the *β's* are the parameters that need to be estimated by the model and *k* is the total number of specified explanatory variables.

However, this variable exhibits skewness as shown in Figure 3-2. A variable with skewed distribution may cause a very low R^2 value in the results. Researchers usually apply some transformation on the commuting distance variable in order to normalize the distribution of data (e.g. Axisa et al., 2012; Buliung & Kanaroglou, 2002; Handy et al., 2005, Maoh & Tang, 2012). Popular methods include square root, logarithm and inverse transformations. Therefore, in order to normalize the distribution of data, the natural log of commuting distance has been taken in this study. It reduced the variance and skewness of the original distribution. In the estimated models, the natural log of commuting distance is taken as the dependent variable. The transformation compresses the variable's long tail, which arises due to the well-known effect of distance decay on spatial interaction intensity. Consequently the model shown in equation 4 becomes:

$$\ln(d_n) = \beta_0 + \beta_1 X_{n1} + \beta_2 X_{n2} + \ldots + \beta_k X_{nk} \qquad \text{(Eq. 5)}$$

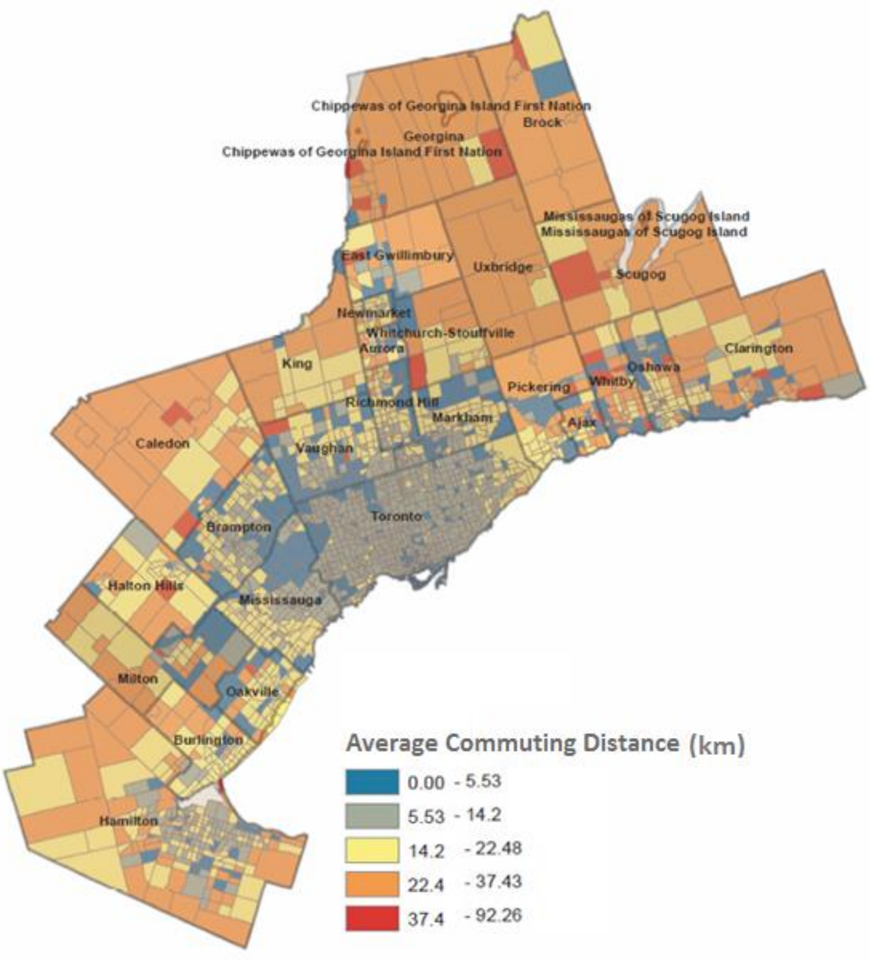

Figure 3-1: Average commuting distance observed for each TAZ.

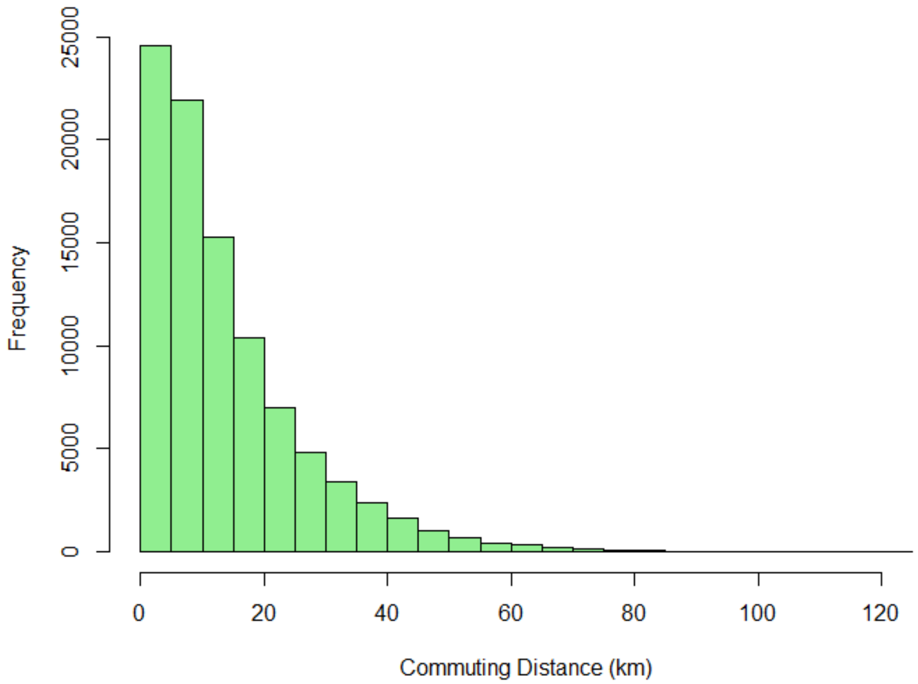

Figure 3-2: Distribution of dependent variable before transformation.

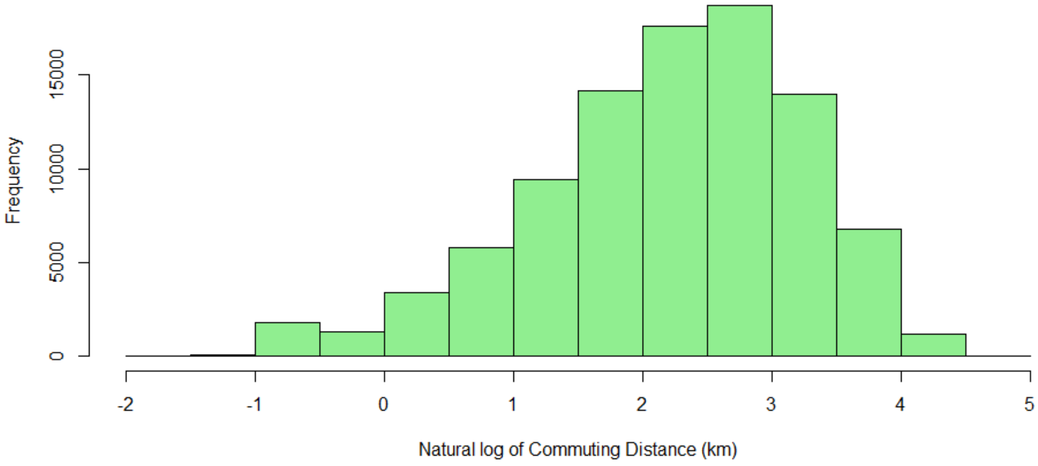

Figure 3-3: Distribution of dependent variable after transformation.

3.2.2.2. Explanatory Variables

A number of demographic, socioeconomic, labour market and land use variables are considered in the specification of the estimated models. The specified variables are based on the information gathered from the literature. Numerous variables have been tested over the years with varying degrees of success. The socioeconomic and labour market variables include the age, gender, mobility status and employment status (full-time or part-time) of workers. Household variables include information on the age of the youngest child, automobile availability, and multi-worker household. Information on the TAZ of residence and TAZ of employment of workers is also included. Variables that were not available in the dataset from TTS were derived using different methods.

Additional variables were required for initial analyses before model estimation and they were constructed using the given dataset, or using information from Statistics Canada. These include multi-worker household and the age of youngest child in household. The multi-worker household variable has been derived from considering those households that have more than one full-time or part-time workers. This variable assumes a value of 1 if person belongs to a multi-worker household, and 0 otherwise. Persons below or equal to age 12 are considered as children in a household. The new variables related to the TAZ consisted of median income of individuals, area of TAZ in square kilometer, number of employed residents, count of firms, number of employees, TAZ Population, distance between TAZ of employment and residence, ratio of jobs to resident workers, and jobs density at the place of work. Calculation for some of these variables is explained below.

Population at the TAZ level has been calculated from the 2011 Dissemination Areas (DA) available from Statistics Canada, 2011 census. The Dissemination Areas is the smallest standard geographic area for which all census data are disseminated, with DAs respecting the boundary of census tracts. However, for this study, the population was required at TAZ level. Therefore the population at the DA level was converted to point data, and summed at the TAZ level. As DAs do not sum up exactly to TAZ level, there were missing TAZs after this step. These missing TAZs were predicted by buffering the surrounding DAs at 2.5 km, and taking the average values. Results are shown in Figure 3-4.

Median income of individuals[2] was available for Census Tracts in GTHA. Therefore, median income of individuals for TAZs in GTHA has been calculated using the "Cross Areal Interpolation" method in ArcMap. Areal interpolation specifically means the reaggregation of data from one set of polygons (the source polygons) to another set of polygons (the target polygons). In this case, the source polygons are census tracts, and the target polygons are TAZs. Reaggregating polygonal data is a two-step process. First, a smooth prediction surface for individual points is created from the census tracts, and then the prediction surface is aggregated back to the TAZ polygons. Results are shown in Figure 3-5 and Figure 3-6.

For calculating JER, the count of firms or companies in the GTHA was taken from the InfoCanada 2011 dataset. It also includes the information on the number of employees in each firm. Using this information, the total number of workers in each TAZ was counted. Information on the number of resident workers was already available from the TTS dataset. Using this information collectively, the ratio of jobs to employed residents has been calculated at the TAZ level using the following formula:

$$\mathrm{JER} = \frac{\text{Number of Jobs in a TAZ}}{\text{Number of Employed Residents in a TAZ}} \qquad \text{(Eq. 6)}$$

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[2] According to Statistics Canada, "the median income of a specified group of income recipients is that amount which divides their income size distribution into two halves i.e. the incomes of the first half of individuals are below the median while those of the second half are above the median. Median income is calculated from the individuals with income in that group (e.g. males aged 45 to 54 years)." (*Source: Statistics Canada, 2001 Census of Population, Statistics Canada Catalogue no. 95F0492XCB2001007).*

Because the JER variable was highly skewed (skewness=102.7), the log of this variable was used. There were 81 observations where a number of jobs in the TAZ was 0, and the log of JER was not possible in those cases. These 81 observations were removed from the dataset, and the log of JER was calculated for the rest of the observations. In the histogram of Figure 3-7, the values on right-hand side of 0 correspond to jobs-rich TAZs. It can be observed that in the whole study area, the majority of employed residents live in resident-rich areas, rather than in jobs-rich areas.

The jobs density of TAZs was also calculated. This is done by dividing the number of jobs in the respective TAZ by the area of that TAZ. It has been calculated for both the TAZ of residence and TAZ of employment of the employed person.

The distance from the CBD was calculated as Euclidean distances between centroids of residence TAZs of commuters to Toronto CBD. Figure 2-9 shows a distinct pattern of commuting distances of commuters by their place of residence. As the distance from Toronto increases, the commuting distances increase as well. Toronto itself is not a monocentric city, however, and the largest concentration of jobs is in the downtown. Therefore, the area near the intersection of Young and Bloor streets was used as the centroid of the CBD.

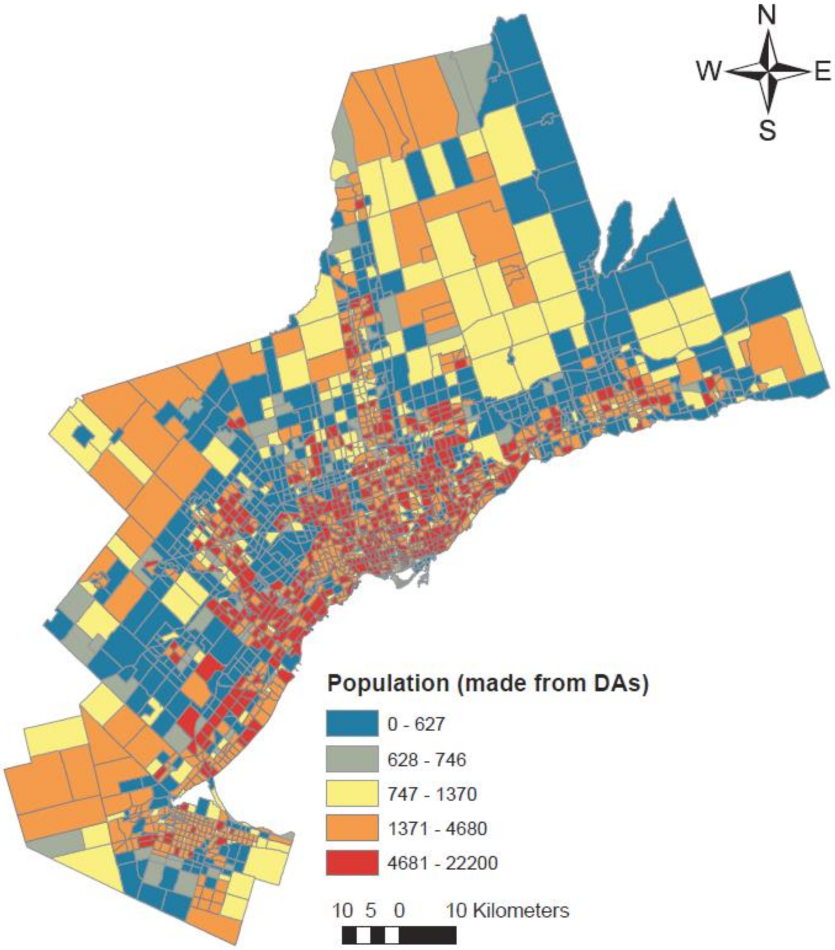

Figure 3-4: Population of TAZs in the GTHA.

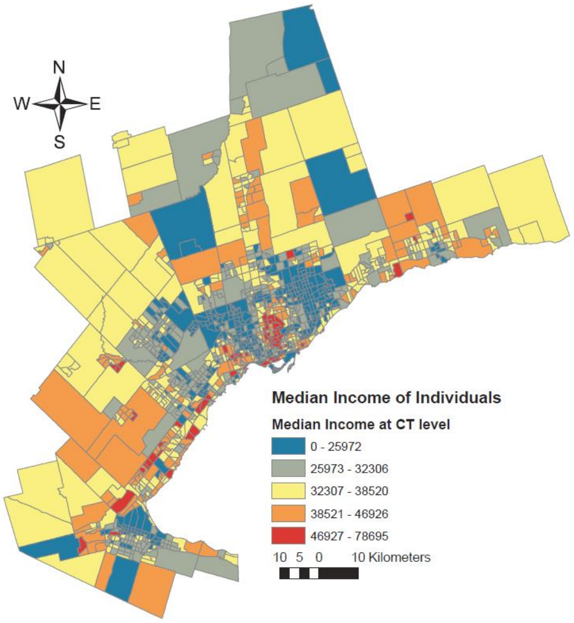

Figure 3-5: Available median income of individuals in 1350 Census Tracts in the GTHA.

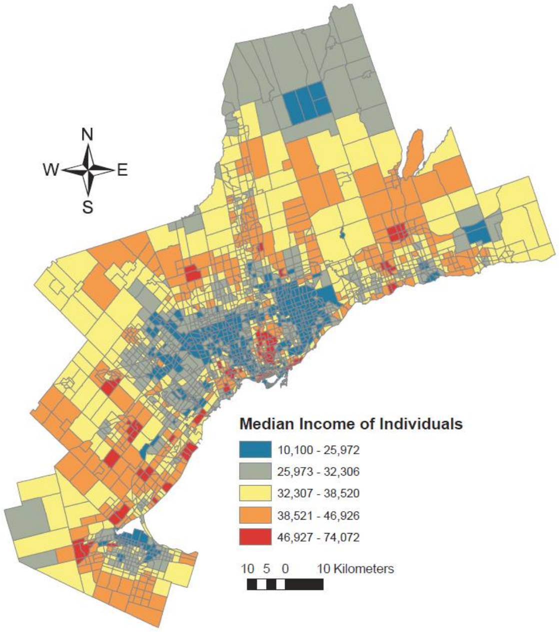

Figure 3-6: Predicted median income of individuals in 2272 TAZs in the GTHA.

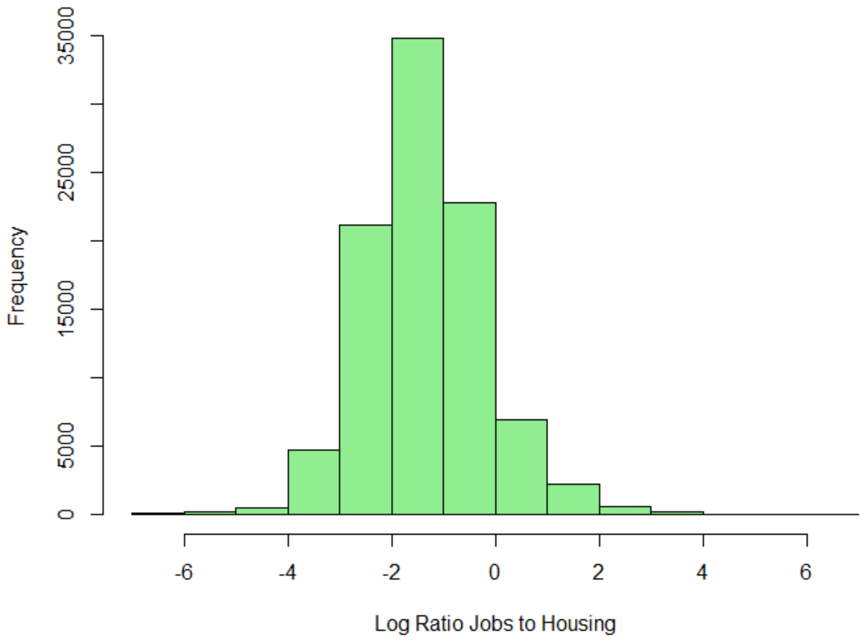

Figure 3-7: Histogram of log of jobs/employed residents' ratio in the GTHA.

Independent variables were checked for correlation with the dependent variable, while selecting variables to be used in the regression analysis. High correlation among independent variables was also examined in order to avoid multicollinearity in the model. Various variables of interest in the dataset were categorical (nominal) and they were represented in the model with dummy variables. For instance, the Auto variable equals 1 if the commuter is using an automobile to go to work, otherwise it is set to 0. The final list and definition of variables, used in the models' estimation, is given Table 3-2. Mean commuting distance is also presented here for various groups.

Table 3-2: Independent variables used in the analysis

Variables	Definition	Mean commuting distance (km)
Socio-economic Characteristics		
Age		
Age 15-19	1 if respondent's age is between 15 and 19; 0 otherwise	6.69
Aged 20-24	1 if respondent's age is between 20 and 24; 0 otherwise	12.04
Aged 25-34	1 if respondent's age is between 25 and 34; 0 otherwise	14.79
Aged 35-44	1 if respondent's age is between 35 and 44; 0 otherwise	14.73
Aged 45-54	1 if respondent's age is between 45 and 54; 0 otherwise	14.16
Aged 55-64	1 if respondent's age is between 55 and 64; 0 otherwise	13.30
Aged 66 plus	1 if respondent's age is above 65; 0 otherwise	11.56
Gender		
Females	1 if respondent is female; 0 otherwise	12.4
Males	1 if respondent is male; 0 otherwise	15.3
Work Status		
Employment Status		
Full Time Employee	1 if respondent is full time employee; 0 otherwise	14.52
Part Time Employee	1 if respondent is part time employee; 0 otherwise	9.29
Student Status		
Not a student	1 if respondent is not a student; 0 otherwise	14.03
Part Time Student	1 if respondent is a part-time student; 0 otherwise	13.27
Full Time Student	1 if respondent is a full-time student; 0 otherwise	7.10

Variables	**Definition**	**Mean commuting distance (km)**
Occupation		
General Office / Clerical	1 if respondent's occupation type is General Office / Clerical; 0 otherwise	14.64
Manufacturing / Construction / Trades	1 if respondent's occupation type is Manufacturing / Construction / Trades; 0 otherwise	14.47
Professional / Management / Technical	1 if respondent's occupation type is Professional / Management / Technical; 0 otherwise	14.89
Retail Sales and Service	1 if respondent's occupation type is Retail Sales and Service; 0 otherwise	12.27
Mobility Status		
Transportation Mode		
Other modes	1 if respondent uses other modes of travel to go to work (like motorbike, taxi etc); 0 otherwise	7.84
Bike or Walking	1 if respondent uses active mode of travel to go to work; 0 otherwise	2.22
Auto	1 if respondent uses automobile to go to work either as driver or passenger; 0 otherwise	14.35
Transit	1 if respondent uses transit to go to work; 0 otherwise	14.86
Driver's License		
No Driver's license	1 if person does not have driver's license; 0 otherwise	8.63
Driver's license present	1 if person has driver's license; 0 otherwise	14.45
Possession of Transit Pass		
Combination or Dual Pass	1 if respondent possesses the Combination or Dual Pass; 0 otherwise	24.86
Go Transit Pass	1 if respondent possesses the Go Transit Pass; 0 otherwise	30.52
Metro Pass	1 if respondent possesses the Metro Pass; 0 otherwise	10.16

Variables	Definition	Mean commuting distance (km)
No Pass	1 if respondent possesses no Transit Pass; 0 otherwise	13.43
Other Agency Pass	1 if respondent possesses any type of Agency Pass; 0 otherwise	17.28
Household characteristics		
Age of youngest child		
No children under age of 12	1 if there are no children in household under age of 12; 0 otherwise	13.42
Age of youngest child 0-4	1 if age of youngest child in respondent's household is between 0 – 4 years; 0 otherwise	15.63
Age of youngest child 5-9	1 if age of youngest child in respondent's household is between 5 – 9 years; 0 otherwise	15.06
Age of youngest child 10-12	1 if age of youngest child in respondent's household is between 10 – 12 years; 0 otherwise	14.53
Multi-worker Household		
Multi-worker Household	1 if more than one person in respondent's household is full/part time employed; 0 otherwise	14.12
Auto Availability		
No Automobile in household	1 if there are no automobile in respondent's household; 0 otherwise	7.31
Automobile available	1 if automobile is available in respondent's household; 0 otherwise	14.37
TAZ characteristics		
JER		
Log of ratio of Jobs to Employed Residents	Natural log of ratio of Jobs to Employed Residents in a TAZ of respondent's residence	
Median Income of Individuals in TAZ		
Median Income of Individuals in TAZ	Median income of individuals living in TAZ of respondent's residence	

Variables	Definition	Mean commuting distance (km)
Jobs Density in TAZ of Employment		
Jobs Density in TAZ of Employment	Jobs Density in the TAZ of respondent's employment	
Population Density in TAZ of Residence		
Population Density in TAZ of Residence	Population Density in the TAZ of respondent's residence	
Distance of residence TAZ from CBD		
Distance from CBD	Straight line distance from residence TAZ of respondent to Toronto CBD	

3.2.3. Assumptions

Table 3-3 shows four categories of trip purpose considered in TTS data, and data displayed here accounts for 5% sample. Only category 1, i.e., Home-based Work trips was considered in this study, which accounts for 30% of the total trips in the GTHA.

Table 3-3: Data distribution for trip purpose in the survey

Category	Trip Purpose	Frequency	Cumulative %	Relative Frequency%
1	Home-based Work	188,715	29.57%	29.57%
2	Home-based School	68,173	40.25%	10.68%
3	Home-based Discretionary	276,435	83.56%	43.31%
4	Non-Home-based trip	104,922	100%	16.44%
	TOTAL	638,245		100%

Other assumptions considered for final dataset selection are described below:

a) Home-based work trips are those where one end of trip is home (i.e. home to work or work to home). These were further narrowed down to trips from home to work.

b) The dataset was narrowed down to contain only the traffic analysis zones with ID less than or equal to 5252. It resulted in only those records that were in the GTHA region, while records belonging to other regions were omitted.

c) As mentioned earlier, the commuting distance has been capped at maximum 90 km, so that the extreme data points may not skew the statistical results. This removes only 42 records of trips by employed persons from the dataset.

d) If a full-time worker did not make a work trip on the trip day, then that record was excluded, because the mode to go to work would not have been available in that case.

e) For the TAZs where the number of jobs was zero, the JER variable gave an error. There were 81 such TAZs where there was no jobs recorded. Those 81 observations were removed from dataset.

f) 2 values were causing residuals of the model to skew to one side. These values were removed from dataset while modelling.

g) For 1,436 observations the TAZ of origin and destination were the same. Because the commuting distance has been calculated as the Euclidean distance between origin and destination TAZ, for these 1436 records, the distance was observed as zero. These separated records were also separately analysed, but they did not provide any significant results.

Following these assumptions, the final dataset consisted of 84,440 observations for home-to-work trips of resident workers in the GTHA.

Other relevant variables or data:

- Employed residents in a TAZ were calculated from the sample using the number of full-time and part-time employees in a household and then aggregating the results at the TAZ level.
- For analysis, the main dataset was merged with the dataset having aggregated information regarding population, income and employment at TAZs level obtained from Statistics Canada and InfoCanada. It was later merged with the "Distance" dataset made in ArcMap which had the calculated Euclidean distance between TAZ of residence and employment.
- For analysis purposes, age groups were created, so that a person belongs to a certain age group.
- Modes of transportation were grouped into four categories for analysis. If mode of transportation was 'Public Transit', 'GO Rail' or 'Joint GO Rail and Public Transit', it was called 'Transit'. If mode of transportation was 'Auto Driver' or 'Auto Passenger', it was called 'Auto'. 'Active' mode was assigned if respondent walked or used a bicycle to go to work. 'Other' group was assigned if respondent used 'Motorcycle, Taxi, School Bus, Other or Unknown vehicle to go to work.

3.3. Model Estimation Results and Discussion

The mean commuting distance for most of the independent variables analyzed in this study is summarized in Table 3-2. First, the average commute distance of workers in the GTHA is 13.9 km. In terms of gender, the average commute distance is 15.3 km for males and 12.4 km for females. These results are in agreement with previous studies such as Champion et al. (2009), Clark and Withers (2002), Green and Owen (2006), and Hanson and Pratt (1991; 1995), who have all indicated that males commute longer distances than females. Age also exhibits an excellent benchmark for comparison to previous studies. The usual trend noted in earlier studies (e.g., Champion et al., 2009; Green and Owen, 2006) is that the middle-age workers have the longest commute. Here, the individuals between the ages of 25-34 exhibit the longest commute. The work status suggests that full-time workers (14.5 km) have longer commutes with respect to part-time employees (9.3 km), whereas those with the occupation type Professional / Management / Technical (14.9 km) have the longest commute with respect to other occupation holders. With respect to mode of transportation, those using transit have the longest commute (14.9 km) whereas those using auto, active or other modes of travel have shorter commutes (14.4 km, 2.2 km and 7.8 km respectively). People possessing GO transit pass exhibit extremely long commute (30.5 km) with respect to other types of transit pass holders. Presence of driver’s license also results in a longer commute (14.5 km) with respect to those not having a driver’s license (8.6 km). The availability of an automobile in the household results in longer commutes (14.4 km) as compared to those commuters that do not have automobile in their household (7.3 km). Workers with no children in the household exhibit the shortest commute distances (13.4 km) when compared to workers having children (15.6 km, 15.1 km and 14.5 km for children aged 0-4, 5-9 and 10-12 respectively) as observed from descriptive statistics in Table 3-2. This result suggests that parents prefer to raise young families in suburban locations, but such locations generally come with longer commute distances. The findings are in line with recent literature in

GTHA (Axisa et al., 2012). Also, the commute distance of workers with children aged 0-4 and 5-9 is found to be greater than the commute distance of workers with children aged 10-12. In other words, as the age of youngest child increases, the commuting distance decreases. Being a full-time student also decreases the commute distance of respondent (7.1 km) as opposed to being part-time student (13.3 km) or not a student (14 km).

As shown in Table 3-4, the analysis starts by estimating the regression model using the full sample of commuters residing and travelling within the GTHA. As discussed earlier, a natural logarithmic transformation of dependent variable d_n adjusts for the skewness in the distribution of values of $d_{n.}$ The total number of records in this sample dataset was 84,440.

The results for the regression analysis in Table 3-4 show that Model 1 only explains 26% of the total variability in the data. Therefore, residual analysis was performed to identify potential outliers. The outliers in this case are the ones having very long commuting distances (positive outliers) or very short commuting distances (negative outliers). Positive and negative outliers were selected based on the calculated residual values when comparing predicted commuting distances from Model 1 to the observed commuting distances already present in the dataset. Following this step, the main sample was divided into subsets of normal and extreme commuters, as well as commuters residing in either resident-rich or jobs-rich areas.

The following steps were taken in order to split the full sample into two groups of normal and extreme commuters. First, the observations that had very high residual values were considered positive outliers. These observations were grouped together into a subset called “Extreme Commuters”. The values less than 25 km were dropped from this dataset. Second, the observations that had small or close to zero residuals were identified as normal observations. A subset called “Normal Commuters” based on these observations was made. The values equal to or greater than 25 km were dropped from this dataset. The mean value of the residuals for the normal observations is calculated and found to be close to zero. Third, the observations having negative outliers were identified and dropped from the dataset, as they were associated with the least amount of commute (mean commuting distance of these values was 2.5 km). Table 3-5 provides summary statistics of commuting distances for the whole dataset, as well as the normal and extreme commuters (i.e. positive outliers). In this study for GTHA, it can be observed from Table 3-5, that the mean commuting distance of normal commuters is 10.8 km, while for extreme commuters, the observed mean commuting distance is 40.9 km. Other studies that have analysed the characteristics of normal and extreme commuters have used different thresholds of commuting distances. For example, in the study by Maoh and Tang (2012), the mean commuting distance is around 5 km for normal commuters, and 17 km for extreme commuters. Green and Owen (2006) treat commutes less than 5 km as short distance. Champion et al. (2009) uses the threshold of 20 km to analyse the characteristics of extreme commuters. Boyle et al. (2001) used a 30 km cut-off, while Findlay et al. (1999) used both 15 and 20 km in their analysis for long distance commuting. It can also be observed that 77% of the main dataset is representative of normal commuters, while only 7.9% represents extreme commuters.

The histogram of the log of jobs-to-employed residents' ratio was used to identify resident-rich and jobs-rich areas in the dataset. The data values that were more than 0 for an area in this histogram show that there are more jobs in that area than the resident workers. 8,740 records of workers were selected for the main dataset, who reside in jobs-rich areas, while 5,057 records were selected having commuters residing in resident-rich areas. Table 3-7 exhibits informative statistics of both jobs- and resident-rich areas, including the mean commuting distance of commuters originating from these areas, the gender distribution as well as the distribution of mode of transportation used for going to work. The mean commuting distance of commuters from resident-rich areas is 18 km, while for commuters from jobs-rich areas, the observed mean commuting distance is 11.9 km. It can also be observed that there is considerable difference in mean commuting distance in both samples. Both samples have about 46% of females with respect to males, so no trend was observed here except for the fact that women in this region are almost equally engaged in jobs as men. In terms of mode of transportation, it was observed that 84.5% commuters from resident-rich areas are highly dependent on auto mode of transport with respect to only 62.6% of commuters using automobile in the jobs-rich areas. Jobs-rich areas have more transit users than resident-rich areas (26.4% vs 14.2% respectively), as well as more active commuters (10.5% vs 1.2%).

In Table 3-4, three multivariate regression models have been estimated. Model 1 is estimated for whole dataset (mean commuting distance = 13.9 km), while Model 2 is estimated for the normal commuters (mean commuting distance = 10.8 km) and Model 3 is estimated for the extreme commuters (mean commuting distance = 40.9 km). Table 3-6 shows estimation of two multivariate regression models. Model 4 is estimated for residents of resident-rich areas (mean commuting distance = 18 km), and Model 5 has been estimated for residents of jobs-rich areas (mean commuting distance = 11.9 km).

The division of the main dataset into subsets greatly helped in improving the explained variability of the resultant models. Model 1 explained only 26% of variation in the data. After splitting it into subsets of normal and extreme commuters, the explained variability became 48% and 45% for these subsets, respectively. The division of the main dataset into resident-rich and jobs-rich areas was also beneficial for Model 5, as Model 4 explained 25%, while Model 5 explained 41% variability in the data.

The first important aspect to notice in all the models in Table 3-4 is that the signs of parameters of variables are consistent for all variables across the three models. It means that the variables used to describe the normal commute can also be used to describe the extreme commute. However, the actual effect of that variable might be larger or smaller. This is also the case with Models of resident-rich and jobs-rich areas.

Age and sex are most consistently used variables in literature for comparison of commuting distances. Sex plays a vital role in explaining housing, travel and labor market dynamics, and it has major implications for planning practice. In Table 3-4 and Table 3-6, all the models show statistically significant results that males commute longer than females. The gender effect on commuting distance in the GTHA is in line with earlier findings from studies done for USA and Canadian regions (Hanson & Pratt, 1991, 1995; Buliung & Kanaroglou, 2002; Clark & Withers, 2002; Maoh & Tang, 2012; Axisa et al., 2012).

As expected, age shows a characteristic inverted U-shape relationship with commute distance. The non-linear behaviour of commuting distance and age is also reported by Morency et al. (2011) and Axisa et al. (2012) for other Canadian cities. Relative to workers who are 15-19 years old (reference group), all age groups have longer commuting distance. The longest commuting distance is observed for the 35-44 age group for Models 1, 2 and 3. In Models 4 and 5, the 25-34 age group shows the longest commute. Younger workers can be attributed as short distance commuters because they probably occupy part-time jobs closer to their place of residence. In addition, they have less chance of owning a vehicle, so they will be more prone to use active transport (walk or cycle), or use public transport to travel short distances to work. All the models show a non-linear behaviour in commuting distance and age. This trend is in line with the findings of Mercado and Páez (2009) for the Hamilton CMA, and Maoh and Tang (2012) for Windsor CMA in Canada.

As expected, the labour market characteristics play a vital role on the commute distance. All models show statistically significant results that part-time employees have shorter commuting distance than the full-time employees. Being a part-time employee reduces the commute distance by 29%, 11%, 24% and 19% for normal commuters, extreme commuters, commuters from resident rich areas and those from jobs-rich areas, respectively. These results are in line with findings from earlier studies (Green, 1999;

Mercado and Páez, 2009; Morency et al., 2011; Maoh & Tang, 2012; Axisa et al., 2012; Newbold, Scott, & Burke, 2015). People with full-time employment have higher income than those with part-time employment, and thus they can afford a longer daily commute.

Variables regarding the mode of transportation have interesting and promising results. From Table 3-8, it can be seen that for the full-sample, the mean commuting distance for Auto and Transit is almost equal (14.4 and 14.9 km respectively). For transit users, the mean commuting distance was 11 km, 43.9 km, 23.8 km and 11.9 km for normal commuters, extreme commuters, and commuters from resident rich areas and those from jobs-rich areas respectively. For auto users, normal commuters had a mean commuting distance of 11.4 km, which shows that normal commuters use auto mode of travel for longer commutes. Extreme commuters using automobiles had a mean commuting distance of 40.7 km, which is less than the mean commuting distance of extreme commuters using transit. The mean commuting distance of auto users from resident-rich and jobs-rich areas show considerable difference (17.3 km and 13.7 km respectively) with respect to mean commuting distance of transit users from these areas. The jobs-rich areas show that the long distance commuters from such areas depend on auto mode of travel. It shows that commuters from jobs-rich areas are commuting shorter distances and preferably use a personal vehicle. Commuters from resident-rich areas are commuting longer distances and for very long commute, they prefer public transit.

The regression results in Table 3-4 show that keeping other variables constant, both normal and extreme commuters use transit when commuting the longest distances, followed by automobile and active mode of travel, with respect to other modes of travel (reference variable). Results from Table 3-6 also shows that the long distance commuters from resident rich areas depend on transit, though they are in very small percentage (14.2%). However, the same is not the case with jobs-rich areas, where 26.4% of commuters use transit, but long distance commuters from such areas are found to depend on auto mode of travel. However, with respect to other modes of travel, people depending on active travel (walk of bicycle) commute shorter distances, as expected. Results of active mode of travel are not significant for extreme commuters.

The results are not in line with previous literature (Dieleman et al., 2002; Buliung & Kanaroglou, 2002; Mercado & Páez, 2009; Maoh & Tang, 2012; Newbold et al., 2015) which report Auto mode of travel used for longest commutes. These results may indicate that the contiguous region of GTHA could be developing differently from other cities in Canada. For example in Windsor 90% of all commuters (83% drivers and 7% passengers) rely on auto to commute (Statistics Canada, 2006). In the study of normal vs extreme commuters, Maoh and Tang (2012) found that auto-dependency has a pronounced impact on extreme commuters for Windsor. In another study, strong relationship was observed between the use of automobiles and longer commutes in a study by Dieleman et al. (2002), in the Netherlands. The common parameter in such studies was that they were done on sprawled cities. Due to rapidly increasing population in GTHA, and restrictions on new developments owing to Greenbelts, the GTHA may be inclined to become a compact region rather than sprawled. In a recent study by Newbold et al., (2015) in Greater Golden Horseshoe, similar results were obtained for impacts on commuting distance, where being an auto driver or using the transit showed almost similar impacts on commute distance of respondent. Individual analysis for each sub-region in this area may produce different and interesting results with the latest data.

As expected based on the literature, vehicle ownership has a positive impact on the distance travelled. Results from Models 1, 2 and 3 suggest that people living in households having one or more automobiles commute the longest with respect to commuters with no automobiles in their household. Model 1 shows that auto availability in household increases the chances of a longer commute by 29% with respect to those commuters that do not have automobile available in their household. Normal commuters with an automobile in their household are 26.5% more likely to travel longer distances than the normal commuters who have no vehicle in their household. The result for auto availability was not significant for extreme commuters.

Models 4 and 5 suggest that commuters from resident-rich areas having automobiles in their household are 40.6% more likely to travel longer distances than the commuters from same areas who have no automobile in their household. However, the commuters from jobs-rich areas having automobiles in their household are only 16.5% more likely to commute longer than commuters having no automobiles in the household. It shows that with auto availability in household, the commuters from resident-rich areas are highly likely to commute longer distances as compared to commuters from jobs-rich areas. This result highlights the importance of mix-use developments and its impact in decreasing the commute distances of workers. All the above results are in accordance to previous studies which show that people who own one or more vehicles are more likely to engage in a longer commute (Dieleman et al., 2002; Schwanen et al., 2004; Cervero & Duncan, 2006; Sultana & Weber, 2007; Watts, 2009; Mercado & Páez, 2009; Manaugh et al., 2010; Morency et al., 2011).

As expected, the presence of a driver’s license results in long distance commuting. For normal commuters, having a driver’s license increases the chances of a longer commute by 18% with respect to normal commuters that do not have a driver’s license. For extreme commuters, having a driver’s license increases the chances of a longer commute by 10% with respect those extreme commuters that do not have a driver’s license. Similarly, having a driver’s license increases the likelihood of long distance commute by 25% for commuters from resident-rich and 14% in case of commuters residing in jobs-rich areas, with respect to commuters not having a driver’s license residing in these areas. These results are in accordance with literature and previous studies (Mercado and Páez, 2009).

Planners and policy makers always promote the ideas that smart growth via mixed land use could indeed help to reduce auto dependency. High levels of residential and commercial land-use mix, and having access to more jobs at the place of residence is expected to reduce the commuting distance (Manaugh et al., 2010). The results from this study are in accordance to this statement. The JER variable shows that commuting distance decreases if the number of employed residents increases in a given area. A 1% increase in Jobs/Employed Residents in a TAZ, keeping all other variables constant, will decrease the commuting distance by 0.07% for all commuters. Similarly, a 1% increase in Jobs/Employed Residents ratio will affect the commuting distance negatively by 0.06% for normal commuters and 0.03% for extreme commuters, keeping other variables constant. These findings suggest that normal commuters would experience more decrease in commuting distance if JER is improved in the TAZ of their residence. A 1% increase in Jobs/Employed Residents ratio in resident-rich and jobs-rich areas will result in decrease in commuters' travel distance by 0.005% (not significant) and 0.03% respectively. These findings suggest that commuters residing in jobs-rich areas would experience more decrease in commuting distance if JER is improved in the TAZ of their residence. These results are in accordance with literature showing the negative relationship between mixed land use and extreme distance commuting (Mercado & Páez, 2009; Manaugh et al. 2010; Maoh & Tang, 2012). However, it should be noted that the effect of JER on commute distance is quite small. This implies that JER does not satisfactorily explain a large portion of observed commuting distances, and large changes in the JER in area would only have a minimal effect on commuting patterns in GTHA.

In a similar manner, the results form Models 1, 2, 3 and 4 (the results from Model 5 are not significant) also show that increasing the jobs density at the TAZ of employment results in a very small increase in the commuting distance. This may be due to the reason that increasing the number of employers in an area may result in a lower density of residential choices in that area or surroundings and lower the land-use mix, again reconciling with the expected results.

High income has a pronounced effect on commuting distance as well (Green, 1999; Prillwitz et al., 2007). For this study, the median income of individuals in a TAZ captures the income of respondent living in the same TAZ. Results from Model 1 as well as the models of normal and extreme commuters show that people with high income commute longer distances. More specifically, when the data is divided into normal and extreme commuters, the impact of an increase in commute distance for extreme commuters is relatively higher than the impact on normal commuters. This result is in accordance with previous studies where higher income increases the likelihood of commuting longer distances by car or transit (Dieleman et al., 2002). It may be due to the reason that people with lower income have lesser chances of owning and using a private vehicle. In addition, people with low income may not have very specialized jobs, and they may be employed at basic jobs near their places of residence. People with high earnings have more chances of vehicle ownership and having specialized jobs which could not be readily available near their places of residence. Their higher income allows for cost justification of commuting longer distances.

Results from Models 1, 2 and 5 show that being part of a multi-worker household results in an increase in commute distance, whereas Model 4 shows a decreasing travel distance if the respondent is part of multi-worker household (results from Model 3 are not significant). The resident-rich areas show a decreasing travel distance with a multi-worker household because the households may relocate themselves to be near the workplace or school of one of the residents, which may promote active mode of travel, thereby decreasing commute distance. In case of jobs-rich areas, the choice of relocation of household to be near job place of one of the residents might not be feasible due to lesser choice of residential locations.

Estimation results for Model 1 and 2 predict the same results that a longer commute is observed for people having younger children (age 0-4), compared to people that do not have children. For commuters having children aged 5-9, the effect for Model 1, 2 and 3 is not statistically different than 0. Model 3 shows that with respect to those extreme commuters that do not have children, the commuters having older children (aged 10-12) commute shorter distances. Presence of very small children may mean that parents are relatively younger, with low income, and cannot afford desired housing near their place of work. This forces them to live much farther away from the place of work. However, it is more likely for people with younger children to own a vehicle because travelling by car is more convenient than using active mode of travel or transit with children. The households without children are less likely to use vehicle to go to work than those who have one or more children. As vehicle ownership results in long distance commute, (Dieleman et al., 2002; Cervero & Duncan, 2006; Sultana & Weber, 2007; Mercado & Páez, 2009; Watts, 2009; Manaugh et al., 2010; Morency et al., 2011), it provides the likely explanation as why the parents of younger children are having such long commute.

To more clearly understand this behaviour, the variable “age of youngest child” was interacted with the “gender”. Results indicate that if the commuter is a male with older children (ages 5-9 or 10-12), his commute is likely to be longer than males having no children. Results were not statistically significant for males having children aged 0-4 for Models 1 and 3. Females have shorter commute than males in any case. The findings are in line with earlier studies promoting the household responsibility hypothesis (White, 1977; Blumen & Kellerman, 1990; Johnston-Anumonwo, 1992; Buliung & Kanaroglou, 2002). A likely explanation may be that because households relocate to accommodate for work place proximity of one of the parents (in case of two-worker household), so most likely women live near their workplace in case of presence of children and men can afford to travel farther. The availability and accessibility of daycares (with accommodations for all age groups of children like infants, toddlers, preschoolers and junior kindergarten), nannies, baby sitters or other family members allows parents to balance work and childcare responsibilities according to their needs.

All the models show statistically significant results that as the distance from the CBD increases, the commuting distance of workers also increases. This result is in accordance with previous studies (Miller and Ibrahim, 1998; Yigitcanlar et al., 2007), where proximity to CBD had a strong influence of the travelled distance of workers.

Additional variables were estimated for Models 4 and 5 in order to clearly understand the factors affecting travel distance of commuters from resident-rich and jobs-rich areas. These variables include student status, occupation, and possession of transit pass.

Models 4 and 5 show that compared to not being a student, a full-time student status results in a decrease in commute distance, however being a part-time student did not return any significant results. For full-time workers, an increase in travel distance was observed, and for full-time students, a decrease in travel distance is observed. Income plays a great role here as students have usually very low or no income while attending university, thus they cannot afford a car. Mostly they prefer to use active modes of travel as opposed to using car or bus to come to university/college daily. For residential purposes, full-time students usually prefer to live in either dormitories or near their educational institute in student rental housings. Thus a reduction in travel distance is observed for these commuters.

Models 4 and 5 suggest that with respect to a General Office / Clerical job, commuters from resident-rich areas with occupation type Manufacturing / Construction / Trades or Retail Sales and Service commute shorter distances. Commuters from jobs-rich areas with occupation type Retail Sales and Service also exhibit shorter commute with respect to people with General Office or Clerical job from same areas. The results are in contradiction with previous studies (Champion et al., 2009; Green & Owen, 2006) which show that occupations associated with low skill levels typically travel shorter than average distances. However this trend was observed only for resident-rich and jobs-rich areas, as the occupation variable did not show any significant results for Models 1, 2 and

3, therefore this variable was not used in the final analyses of those models. One of the reasons for this observed shorter commute by skilled workers can be that people with specialized jobs usually have higher income than the ones having clerical jobs, giving them option to live nearer to their place of work. This justifies the long distance commute observed for these commuters of resident-rich or jobs-rich areas.

Possession of a transit pass also resulted in interesting results for of resident-rich or jobs-rich areas. Results from Models 4 and 5 show that with respect to possessing a combination or dual pass, the commuters with metro pass, any other agency pass or even no pass have a shorter commute. However, commuters from jobs-rich areas having a GO Transit pass[3] are more likely to undertake a longer commute. GO transit has routes extending to communities across the Greater Golden Horseshoe, and this explains the preference of using this regional transit for people having very longer commute.

Population density variable also showed significant results in Models 4 and 5. Increasing population density in the residence TAZ also contributes towards a shorter commute distance for residents of these areas, as indicated by a negative coefficient signs. These results are interesting to compare with previous studies, like Cervero and Kockelman, (1997), Limtanakool et al. (2006) and Morency et al. (2011). Limtanakool et al. (2006) showed that the participation in medium– and long–distance travel is affected greatly by local population density. Morency et al. (2011) had noted that in Canada, a higher population density has a negative impact on travelled distance in Montreal and Hamilton, while a positive impact on travelled distance in Toronto. As our study area is the whole GTHA, individual analysis of the impact of population density on commute distance for sub-divisions in GTHA may produce different results for each.

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[3] As recently as 2012, Metrolinx has discontinued the monthly GO passes, and converted to PRESTO electronic fare card, that can be used in all GO trains, buses as well as other local transit systems. This study is using data from 2011, therefore use of GO transit pass is being shown here.

3.3.1. Future Work

This study demonstrates that the selected approach is sensitive to the location decisions of individual commuters. The disaggregated approach undertaken to analyse the factors behind the changing commute distance was for the whole study area. However, each municipality in GTHA has individual policies pertaining to land use and transit. Therefore, further investigation of disaggregate data within each municipality or CSD would bring insightful results about areas that need focus in the long run to promote an appropriate commute distance for workers.

Table 3-4: Estimates of multivariate regression models for normal and extreme commuters, 2011.

	Model 1 (Entire dataset)	**Model 2** (Normal commuters)	**Model 3** (Extreme commuters)
	Estimate	**Estimate**	**Estimate**
(Intercept)	0.2318 ***	0.4674 ***	2.643 ***
Gender			
Females			
Males	0.1817 ***	0.1344 ***	0.1277 ***
Age			
Age 15-19			
Aged 20-24	0.3466 ***	0.3573 ***	0.0754 *
Aged 25-34	0.4601 ***	0.4632 ***	0.1611 ***
Aged 35-44	0.4781 ***	0.4729 ***	0.1645 ***
Aged 45-54	0.4601 ***	0.4671 ***	0.1402 ***
Aged 55-64	0.4228 ***	0.437 ***	0.1208 ***
Aged 65Plus	0.3484 ***	0.3712 ***	0.1088 **
Driver’s License			
No Driver’s license			
Driver’s license present	0.2175 ***	0.1867 ***	0.1034 ***
Employment Status			
Full Time Employee			
Part Time Employee	-0.3153 ***	-0.2865 ***	-0.1086 ***
Transportation Mode			
Other modes			
Bike or Walking	-0.9874 ***	-1.002 ***	0.1024
Auto	0.4687 ***	0.5773 ***	0.2518 ***
Transit	0.7349 ***	0.7512 ***	0.3663 ***
Auto Availability			
No Automobile in household			
Automobile Available	0.2902 ***	0.2656 ***	0.0309
Age of youngest child			
No children under age of 12			
Age of youngest child 0-4	0.0448 **	0.0430 ***	0.0152
Age of youngest child 5-9	-0.0241	-0.0116	0.0102
Age of youngest child 10-12	-0.0312 .	-0.0230 .	-0.0401 *

Multi-worker Household			
Not a multi-worker household			
Multi-worker Household	0.0213 **	0.0154 **	0.0066
Log JER			
Log of Jobs to Employed Residents Ratio	-0.0744 ***	-0.0604 ***	-0.0251 ***
Median Income of Individuals in TAZ			
TAZ Median Income of Individuals	4.50×10^{-6} ***	4.113×10^{-7}	2.70×10^{-6} ***
Jobs Density in TAZ of Employment			
Jobs Density in TAZ of Employment	1.14×10^{-6} ***	7.835×10^{-7} ***	1.515×10^{-7}
Distance of residence TAZ from CBD			
Distance from CBD	0.0107 ***	0.0075 ***	0.0089 ***
Sex x Age of youngest Child			
Male x No child			
Male x Age of youngest child 0-4	-0.0142	-0.0405 **	2.441×10^{-4}
Male x Age of youngest child 5-9	0.0845 ***	0.0449 **	0.0398 *
Male x Age of youngest child 10-12	0.0931 ***	0.0462 **	0.0602 **
No. of Observations	84,440	65,037	6,628
Adjusted R^2	0.2627	0.4848	0.4489

Significance level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 3-5: Commuting distance statistics for normal and extreme commuters in the GTHA, 2011.

No. of observations	**All Commuters**	**Normal Commuters**	**Extreme Commuters**
	84,440 (100)	65,037 (77)	6,628 (7.85)
Commuting Distance (km)			
Min	0.19	0.26	25
Max	89.7	24.9	89.7
Mean	13.9	10.8	40.9
Median	10.3	9.82	38.34
Std. Deviation	12.2	5.9	11.9

Note: Numbers in brackets represent percentages

Table 3-6: Estimates of multivariate regression models for residents of jobs-rich or resident-rich areas, 2011.

	Model 4 (Resident-Rich)	**Model 5** (Jobs-Rich)
	Estimate	**Estimate**
(Intercept)	1.348 ***	1.224 ***
Gender		
Females		
Males	0.2243 ***	0.1658 ***
Age		
Age 15-19		
Aged 20-24	0.0497	0.1522
Aged 25-34	0.2369 .	0.2839 **
Aged 35-44	0.2351 .	0.2556 *
Aged 45-54	0.2157 .	0.2633 **
Aged 55-64	0.1803	0.2433 *
Aged 65 plus	0.1275	0.0828
Driver’s License		
No Driver’s license		
Driver’s license present	0.2469 ***	0.1386 ***
Employment Status		
Full-time Employee		
Part-time Employee	-0.2359 ***	-0.1946 ***
Transportation Mode		
Other modes		
Bike or Walking	-0.6274 .	-0.9309 ***
Auto	0.58 .	0.8875 ***
Transit	0.7807 *	0.8688 ***
Auto Availability		
No Automobile in household		
Automobile Available	0.4063 ***	0.1653 ***
Multi-worker Household		
Not a multi-worker household		
Multi-worker Household	-0.0479 .	0.0908 ***

Log JER		
Log of Jobs to Employed Residents Ratio	-0.0049	-0.0324 **
Jobs Density in TAZ of Employment		
Jobs Density in TAZ of Employment	1.27×10^{-6} ***	-1.59×10^{-7}
Distance of residence TAZ from CBD		
Distance from CBD	0.0091 ***	0.0059 ***
Population Density in TAZ of Residence		
Population Density in TAZ of Residence	-5.64×10^{-5} ***	-9.25×10^{-6} ***
Possession of Transit Pass		
Combination or Dual Pass		
Go Transit Pass	0.0457	0.4117 ***
Metro Pass	-0.3953 ***	-0.5727 ***
No Pass	-0.4599 ***	-0.6121 ***
Other Agency Pass	-0.3402 ***	-0.4449 ***
Occupation		
General Office / Clerical		
Manufacturing / Construction / Trades	-0.214 ***	0.00315
Professional / Management / Technical	-0.0403	-0.0187
Retail Sales and Service	-0.1602 ***	-0.1493 ***
Student Status		
Not a student		
Part-time student	0.0464	-0.0094
Full-time student	-0.2673 *	-0.1869 *
Number of observations	5,057	8,740
Adjusted R-squared	0.2504	0.4108

Significance level: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 3-7: Commuting distance statistics for residents of jobs-rich and resident-rich areas in the GTHA, 2011.

Observations	**Resident-Rich Areas**	**Jobs-Rich Areas**
No. of commuters	5,057	8,740
Commuting Distance (km)		
Mean	18	11.9
Median	15.1	8.3
Std. Deviation	13.3	11.8
Sex (count)		
Females	2,315 *(45.8%)*	4,089 *(46.8%)*
Males	2,742 (54.2%)	4,651 *(53.2%)*
Mode of Transportation (count)		
Other	6 *(0.1%)*	47 *(0.5%)*
Active	60 *(1.2%)*	916 *(10.5%)*
Auto	4,271 *(84.5%)*	5,468 *(62.6%)*
Transit	720 *(14.2%)*	2,309 *(26.4%)*

Note: Numbers in brackets represent relative frequency in each group

Table 3-8: Comparisons of commuting distances

	Average Commuting Distance (km) for different commuters				
Mode of Transportation	**All Commuters**	**Normal Commuters**	**Extreme Commuters**	**Resident-Rich**	**Jobs-Rich**
Auto	14.35	11.44	40.67	17.3	13.7
Transit	14.86	10.97	43.86	23.8	11.9

4. CONCLUSION

This study has advanced the knowledge surrounding commuting behaviour by focusing on socioeconomic, labour market, travel behaviour and land use determinants of commute distance in the GTHA using the most recently available datasets. It reinforces certain results in the literature while providing new insights into commuting by combining analyses on normal and extreme commuters as well as commuters from resident-rich or jobs-rich areas.

Descriptive analysis in this study was conducted at the CSD level in the GTHA for analysing self-containment, outbound commute, inbound commute, jobs and resident employees' densities, and average commute distances for place of residence and place of work of resident employees. These descriptive results showed that Toronto and Hamilton CSDs are highly self-contained, where 81% and 70% of resident workers commute within their respective CSD. An additional 37.9% of commuters from the other CSDs in the whole study area commute to Toronto, whereas Hamilton attracts only 1.2% additional commuters from all other CSDs. Areas located in the north and northwest of Toronto are major sources of outbound commutes, such as King (92%), East Gwillimbury (87%) and Uxbridghe (87%) CSDs.

Toronto accounts for 40.1% of employed residents and 49.7% of jobs of whole study area. Other areas like Mississauga (11.2% and 13.7%), Brampton (8.3% and 5.2%) and Hamilton (6.8% and 5.3%) also have high numbers of respective employed residents and jobs with respect to whole study area. However these numbers are very small as compared to Toronto. The highest jobs density was observed in Toronto (1492 per sq.km) followed by Mississauga, Newmarket and Markham (408.4 to 901.1 per sq.km). The highest employed residents density was observed for Toronto as well, (1204.3 per sq.km), followed by Mississauga, Newmarket, Brampton, Richmond Hill and Ajax, ranging from 430.2 to 733.3 per sq.km.

Toronto, Vaughan, Mississauga, Brampton, Hamilton and Markham CSDs show a lower average commuting distance for place of residence, ranging from 10 km to 14.6 km. Residents of Uxbridge, Georgina and Brock commuted exceptionally long distances to go to work in the GTHA (28.4 km, 32.5 km and 34.5 km, respectively). Workers commuting to Hamilton and Oshawa showed a lower commuting distance (8.9 km and 10.6 km respectively), while workers commuting to Uxbridge, King and Brock commuted longer distances on average to go to work (18.6 km, 19.3 km and 20.8 km, respectively).

With increasing population in the GTHA and changes in land use and socioeconomic conditions, increasing commuting distances and extreme commuting has become a major issue. Overall, the higher average commuting distances by place of residence in the GTHA ranged from 21.2 to 34.5 km; whereas the higher average commuting distance by place of work ranged from 15.4 to 20.8 km. In order to examine the factors affecting commuting distances, the use of a disaggregate approach results in determining the real commuting situation for individual workers. Therefore, five models have been estimated at disaggregated level in this study to examine factors affecting the commuting distances of resident workers in GTHA. The main findings from the models estimation can be summarized as follows: (1) Impacts of most socioeconomic and labour market factors on commute distance observed in GTHA are in line with numerous earlier studies conducted on commute distance determinants, (2) Commuters from GTHA are dependent on transit for longest commutes, (3) Workers living in Jobs-rich areas with occupation type Sales and Service are commuting shorter distances with respect to other general occupations.

In summary, the results from all models indicate that the longest commute is observed for full-time employees, high wage earners, males, and age group 35-44 (for normal and extreme commuters) and age group 25-34 (for commuters from resident-rich and jobs-rich areas). Other contributing factors for long commutes are the presence of driver’s license, males with older children, commuters belonging to multi-worker households, availability of automobile in the household, increasing distance from CBD and increasing jobs density in the TAZ of employment. Workers employed in the General or Clerical jobs exhibited the longest commute with respect to other types of occupations and living in resident-rich areas. A decreasing travel distance was attributed towards factors like part-time employment, active mode of travel, vehicle unavailability in household and higher JER in the residence TAZ. For commuters from resident-rich and jobs-rich areas, additional factors affecting shortening the commute distance of workers were full-time students, higher population density in residence TAZ and use of active mode of travel. Long distance commuters using transit usually have GO transit pass. The negative relationship between the ratio of jobs to employed residents (JER) and commuting distance in all the models leads us to conclude that auto dependency could be restricted through smart growth and mixed land use. Land use mix cannot be realistically incorporated in each and every neighbourhood of GTHA. However, certain centres producing very long distance commute can be targeted to incorporate ease of transit for general public as well as promoting polycentrism, thereby shortening the travel distance in the long run.

Results of this study show the latest trends of commuting patterns in the GTHA. Workers having occupations in Sales and Service and living in Jobs-rich areas exhibited shorter commute than those in General/Clerical occupation. Transit seems to be the preferred mode of travel for long distance commuters. Only the commuters living in Jobs-rich areas showed the usage of Auto mode of travel. In resident-rich areas, transit users are lower in number with respect to auto users, but long distance commuters from these areas nevertheless rely on transit as indicated by the regression results. These results show a very positive impact on mode of commuting for residents of GTHA, where policy efforts have been made for a long time to promote transit-oriented development and make it accessible for public, and affect the public travel habits in a positive manner. These results also show that GTHA is becoming very different in terms of commuter behavior from sprawled sized cities in North America.

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